TEACHING FEMINIST APPRAISALS OF HISTORY, PHILOSOPHY, AND CONTENT OF SCIENCE

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Various feminist perspectives on science have brought to attention regressive dimensions of the ever-progressing scientific enterprise. Focussing the feminist lens on the history and philosophy of science has helped to explain not only the conspicuous absence of women and other marginalised groups from scientific practice, it has provided us important tools to study and analyse the role science plays in both reinforcing and subverting existing oppressive social relations and institutions. Motivated by the belief that these perspectives have immense educational value, I incorporated them in teaching elementary school science in a teacher education course. Based on this experience, I contend that feminist appraisals of traditional history and philosophy of sciences should be taught in science classrooms which are embedded in societies that are marked by divisions along the axes of gender, class, caste, race or religion.

Introduction

History and philosophy of science have been shown to contribute immensely to a meaningful and effective science education. Historical and philosophical approaches to teaching the subject not only humanize science for students who otherwise believe it to be happening in a distinctly aloof world, they help make it attractive to those groups of students who have traditionally found it dull and difficult. It has been shown that these approaches make science classrooms more challenging and exciting wherein students can learn and improve their critical thinking and reasoning skills. At the same time, history and philosophy of science or HPS approaches also assist teachers in improving their understanding of science and thus improving their science teaching. Teachers who have had HPS informed training better anticipate and deal with mis-/alternative conceptions and learning difficulties of their students (Matthews, 2015).

My initiation into this field of scholarly work happened through my engagement with feminist perspectives on science. Feminist scholarship successfully explains the excesses and dynamics of science by recourse to its history. Focussing the feminist lens on the history and philosophy of science has brought to fore regressive dimensions of the ever-progressing scientific enterprise which, I believe, have a lot of educational value. In this paper, I argue that although exposing students to the rich and diverse history of science and discussing philosophical aspects of scientific knowledge are sound proposals both theoretically and empirically, they are not enough. An adequate science education ought to illuminate all aspects of science, and incorporating feminist theories *about* science serves that purpose well. In order to do this, I reflect on my experience of teaching elementary school physics and chemistry to prospective teachers in a teacher education programme at a Delhi University College. In the first section of my paper, I very briefly describe the contributions that feminist theory has made to studies of science which provided a framework for raising these issues in the classroom. In the second section, I describe and reflect on my experience as a teacher educator using HPS and feminist criticisms of science in my lessons. Based on this experience, I assert that complete science education requires not just understanding of scientific knowledge and the different processes through which it is established or modified, but it necessitates the inclusion of a critical, feminist perspective on science too.

Feminist contributions to science

Over the past forty years, feminists have expressed a number of distinct perspectives on science. They have articulated positions that reveal a variety of gender-based forms of biases that have characterized modern scientific endeavour. These feminist critiques can be classified into three broad categories (Keller, 1982; Kohlstedt & Longino, 1997; Matthews, 2015). First, is the issue of near to complete absence of women from conventional histories and contemporary practice of science. Efforts are on, ranging in their scope from institutional to governmental, to redress this gap in scientific disciplines and science textbooks. Secondly, feminists have identified sciences as both a source and a locus of other kinds of gender inequalities which abet reproduction of gender binaries in society. Feminist critics of science have found that women and gender are routinely marginalized as subjects of scientific inquiry, or are treated in ways that reproduce gender-normative stereotypes, and then these 'scientific' stereotypes serve to rationalize the kinds of social roles and institutions that feminists often challenge. Other feminists have questioned the soundness of knowledge that is produced in different scientific disciplines by exposing how gender ideologies of scientists creep into different stages of their rational, objective scientific work-for example, from selecting a portion of reality to study, to describing it in certain terms, to framing testable hypotheses, and drawing inferences from observations (Doell & Longino, 1983; Koertge, 1980).

Going a step further from criticising extant science structures and institutions, some feminist scholars allege that scientific epistemology and methodology have deep masculine biases. This is the third level of feminist critique, and the most controversial one (Sur, 2001; Kohlstedt & Longino, 1997). Those who subscribe to this position have responded in two different ways. One group believes that despite its faults, science is an important social enterprise which can be reformed keeping the traditional scientific canon intact, although steps should be taken to organise scientific activity in more democratic ways. Scholars like Evelyn Fox Keller (Keller, 1985), Anne Fausto Sterling (Longino & Hammonds, 1990), and Helen Longino (Longino, 1989) fall into this category. Ways to achieving a better and more just science include fostering a self-reflexive attitude among scientists, seeking representations of nature which are characterized by interaction, interdependence, and diversity, and ensuring that scientific community is as diverse as possible. The other group dismisses these suggestions as petty reformism and roots for a radically different scenario in modern science is advised to drop its claims to universality and superiority over other knowledge systems. Sandra Harding (Longino & Hammonds, 1990) champions this radical feminist position and calls for dethroning traditional conceptualisations of modern science which she believes are masculine and hegemonic. She argues instead that each culture should develop its own system of generating and organising knowledge about the world and resist the homogenizing tendencies of western science (Bartsch, 1999).

As outlined above, there are various feminist appraisals of science and it would be a mistake to assume that all feminists who go beyond the ‘number issue’ are anti-science. As a critical perspective, feminism and theories inspired by it seek to improve existing ways of science and society. But both of these projects are also contingent on a much-improved system of education, particularly that of science education. Reforms are underway and good will can certainly be acknowledged, and, as I discuss in the next section of my paper, an engagement with feminist criticisms of science in science education has the potential to kick-start this process of changing science and society.

Engaging with history and philosophy in the science classroom

Earlier this year I got an opportunity to teach a paper titled ‘core natural science’ to a class of students who were training to become elementary school teachers. This paper consisted of topics from elementary school curriculum of physics, chemistry, and biology as found in most school science textbooks in India and elsewhere. I had to teach physics and chemistry to a group of 55 girls in the age group of 17-19 years; biology was taught by another teacher. It was mandatory for all of them to revisit school level science as part of this paper in order to teach a subject of their choice later.

I began with implementing HPS inspired ideas in my teaching because of impressive research that advocated its inclusion and making students appreciate the human element of science. The initial motivation was to present the subject differently to students as compared to how they had studied it earlier in school. For instance, to introduce the subject of electricity, I used excerpts from Henry Schlesinger’s book “The Battery” which provides an interesting early history of diverse experiments with electricity in Europe in the 18th and 19th century. Websites such as atlas obscura, the public domain review were used as sources for historical images and interesting snippets. The “International handbook of research in history philosophy”, and “Science teaching- volume I” edited by Michael Matthews was regularly consulted as a source for historical and philosophical knowledge on other topics such as energy/work, mechanics, and heat and temperature.

Philosophy often found its way when we, quoting Matthews (2015), ‘slowed down the science lesson and asked what terms meant and what the conditions were of their correct use’. The process got off to a good start. Most science learning and teaching in India is quite traditional and hence my students seemed to enjoy the different experience of a science classroom. They were listening intently to the historical episodes, were actively questioning concepts, asking for clarifications, and generally participating in the discussions. Surprising was the observation that those students whom other teachers had considered to be less participative were interacting too. Another benefit this approach had was that it helped fire imagination of students, which is usually encouraged in arts or literature classrooms. Interestingly, this imagination was not geared towards finding innovative solutions to scientific problems but helped them place themselves in those historical times and personalize the experience of doing science. It helped generate thoughts and ideas which were much more organic and real. Such a virtual journey into some episodes of modern science made them feel more connected to the science they were learning and to the circumstances in which it was created.

But I soon realized my task was cut out a bit different from just engaging students in my subject matter. I was teaching in a minority institution, which meant that affirmative action policies for students with certain social backgrounds brought some of those students to the classroom who could not have met general merit-based requirements. This fact warrants a mention because a couple of weeks into my teaching, I was informed by my senior colleagues that a good number of students drop out after their first year of college. They reasoned that this was so because it gets increasingly difficult for them to keep up with curricular demands. Unfortunately, this phenomenon is too common in Indian universities and research institutions wherein students who lack the necessary cultural, social, and economic capital often drop out for not being able to cope with the demands of the so-called elite institutions (Chanana, 2007).

Most of my students did not choose to study science at senior secondary level (Grade 11 and 12). This was expected given that patriarchy has a deep hold on Indian society, and girls are not encouraged to have fulfilling professional careers of their choice. Learning and doing science is an expensive affair, hence a lot of girls have to drift out of the subject at the earliest exit route (Chanana, 2007). There was a real chance that for some girls this was their last science course. At the same time, science and technology have come to assume a pride of place in the Indian imagination with the prime minister himself championing slogans like 'Make in India' and 'Digital India'. Given this context, it was important that my students learn to have an informed opinion on science and technology related issues. Therefore, keeping all these factors in mind, I decided to discuss feminist perspectives on science with them. The decision was also motivated in part by recent ideas in science education literature that propose teaching science as culture which helps students "find individual access to sciences and generate individual interests that are related to sciences" (Heering, 2016, p 747).

Bringing in the feminist issues

One entire unit in the course syllabus was dedicated to discussing different aspects of scientific knowledge such as theories, laws, facts, and hypotheses, or broadly, some elements of nature of science. I decided to weave feminist criticisms of science around these issues. There is a standard text which is shared with students in my department, a chapter on nature of science from the book 'science instruction in the middle and secondary schools' by A. T. Collette and E. L. Chiapatta. The class opened with a few questions I had borrowed from this chapter to get them thinking about themes like explanation, prediction, significance of experiments, and validation in science. The aim was to trigger their thinking about dynamics of knowledge generation. This discussion paved the way for scrutinising the role of (background) assumptions in providing and accepting explanations for any chosen phenomenon. It also provided a way for us to understand how values and conventions inform the reasons we give and accept to make sense of a piece of reality.

Opening up of the scientific discourse this way was followed by watching a TED Talk by the Oxford astronomer Jocelyn Bell Burnell on women and science. This talk covers a range of issues from bitter experiences of individual women in science courses to a hostile culture of science for those women who persist in the field. Most students could not connect to what she was saying for they were obviously not in a science course and indeed times have changed since the 1950s, but some echoed the concerns she raised about how girls who perform well in science and math get labelled in mixed-sex educational settings. Such concerns have been reported to be prevalent among school students in England too who although believe that all girls are capable of doing well in science but at the same time they were assumed and expected to be less girly or less feminine (Archer et al, 2013; Francis et al, 2016).

From this discussion of ‘women in science’ issues emerged related concerns of nature of science. Harding’s (1986) exposition of how these ‘liberal’ concerns of getting more women to science point to deeper issues in the scientific canon provided a few questions that I used to bridge these two aspects. The students were asked to wonder about the possibility if there is something about science itself that contributes to such similar cross-cultural articulations about girls in science. They were asked to reflect on their experience with school science. Interestingly, some who did not pursue science at senior secondary level remarked that they did not like the emphasis on one correct answer in science (and math) and that science was boring. Those who did study science at senior secondary levels were smiling at such statements.

For the next part of my teaching, I had aimed to show how gender ideologies have biased what we know and how we know. This was an attempt to bring together the previous two parts of this unit. I referred to two particular internet sources for this section- shipseducation.net and the project website of Gendered Innovations. They allowed for discussion of themes such as value-ladenness of facts, theory-ladenness of observations, how and where do biases enter the scientific knowledge generation, how nature of explanation differs in different disciplines of science, and how science as we know today is a product of years of churning and changes. Subsequently, I wrote down a few more questions inspired by feminist scholarship such as:

Please name a few scientists we have mentioned in our classes so far.

Why it is that most of these scientists are male?

What kind of features and values do you associate with science?

Whose questions are investigated or considered worth scientific investigation?

What kinds of methods are considered worthy of scientific practice?

To whose benefit is scientific knowledge put?

Does it matter if a scientist is male or female? Upper caste or from lower one? Black or white or brown?

Is there any relation between scientific change and social change?

Is it possible to engage in scientific theorising that does not intimately articulate with existing social distributions of power?

Koertge (1980), Longino & Doell (1983), Schiebinger (1987), Keller (1985), Bal (2002), and Crasnow et al (2005) were used as primary resources for informing the discussion of these issues. They helped us understand how gender can be analysed into each of these themes in actual scientific knowledge, its history, and epistemology.

My students were mainly quiet and contemplative during this time. It can be safely said that these questions had stirred their minds. One of them broke the silence by wondering aloud “why did we not think of this earlier?" Another one remarked, "This is very interesting and different, I never thought like this." The overall class environment was punctuated with surprised, suppressed, and in some cases, I-knew-it-all-along smiles.

Maybe because they were all young women, fresh out of school, who were in the process of developing a critical perspective, such a discussion of issues that brought together two seemingly disparate subjects provided them a new way of looking at things. It added to their repertoire of cognitive tools to make sense of what was happening around them. They experienced what I had when I first learnt about this field of study after my masters in chemistry – how social structures were not equally friendly to everyone and how the epitome of knowledge which is supposed to stay above and beyond the social actually has deep and strong ties with it.

These questions and the discussion they generated afforded us the chance to discuss the historical and constructed nature of scientific institutions, methods, beliefs, and practices. We also learnt that it is recommended for a scientist to be aware of his/her own assumptions or stay open to the possibility of confronting them when others point them out (Longino, 1989). Exposure to these feminist ideas also made some students conscious of their own gender in new ways. In the current discourse of equality of opportunity, many urban girls often feel that they can do anything they want, but from the experiences of women scientists they learnt that one's gender does not just disappear when they are doing science (Sur, 2001), and an awareness of this helps one navigate both their professional and personal lives better.

As has been pointed out in Brotman & Moore's (2008) extensive review of the literature on girls and science education, the challenge lies in "attracting students to science *and* asking them to be critical of it" (p. 988). I was aware of not seeming too critical of the scientific enterprise but I also wanted to underscore the fact that individual problems often have historical origins and a wider, social presence. And most importantly, there is nothing inherently male about doing science and being a scientist, for science fundamentally is about asking questions and seeking answers.

Conclusion

In this paper, I have tried to tread a 'middle path' by addressing the simplistic understanding of feminist critiques of science as anti-science as has been exemplified in Shah & Chadha (2011). Until feminists arrived on the scientific scene, the lopsided nature of scientific profession was not a major issue. When it started to get addressed, the omissions and misrepresentations in scientific knowledge started becoming legible. Primatology, evolutionary biology, developmental biology, molecular biology, endocrinology are some such disciplines wherein feminist critical voices have been raised and heeded.

To conclude, I want to emphasize that we need to expand the notion of science education to include feminist appraisals of science too, along with using history and philosophy of science. The political significance of what to teach and how to teach has been well established (Apple, 2013; Mayberry, 1998). Therefore, the inclusion of feminist criticisms of science in science education is certainly valuable if we aim to transform current unequal relations in science and the larger society. Feminist theories have brought to our attention subtle ways in which science and society interact with each other. This knowledge can be used to make critical students who are able to exercise their rational faculties of mind not only in deciding between different knowledge claims (Bailin, 2002) but also in analysing and transforming the oppressive relations and dynamics that characterise their own lives (Mayberry, 1998).

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THE QUESTION OF VALUE IN SCIENCE EDUCATION

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What is the question of values in science education? Is there one? Like all human endeavours, science too entails – implicitly or explicitly – a set of values: some may, for instance, argue that scientific observations are "theory laden" [e.g., (Hanson, 1958)], some others may emphasize the ethics of doing science understood as the code of conduct or 'ethics' of scientific research [Cf. (Mukhi, 2016)]. How do we conceptualize the question of value in science education – what are we reflecting on when we think of values in science [not merely value of science], when we value science qua students of science. The paper thus raises and reflects on the question of value in science education. Answering it is beyond the scope of this paper – it may not be fruitful to even attempt it in the available short space and time. But if the question is raised and reflected on with a sharp [but not narrow] focus, it is more likely than not to illuminate the right answer.

> "Our young geniuses are passionately ambitious instead of being passionately passionate; and it has become very difficult to distinguish between what is an ardent search for truth and what is a vigorous promotion campaign. What started as an adventure of the highest has become the survival of the slickest or the quickest. "Cloak and dagger" has changed to "cloak and suit". We now have DNA tycoons and others have "made a killing" in RNA… the feeling to be a pioneer at no extra cost… A generation of scientific quiz kids knowing the answer to everything… a time in which everything that is new is true … the general sloganification of science… great names can substitute for great concepts … Mix anything with everything in the right proportions and the resulting puree will say: Papa!" (Chargaff, 1963, pp. 176-77, 183, 185)

> "Late modernity proliferates uncertainties; radical uncertainties mark the venues from which techno scientific futures emerge … solutions to the problem of knowledge are solutions to the problem of order" (Shapin, The Scientific Life, 2008, pp. 5, 264)

> King Rajavahama smiled. "Behold!" he said, "adultery aided by trickery has become a legitimate means to ensure and enhance both virtue and fortune. In your hands it could cause your parents to be freed from evils of captivity, help destroy a wicked enemy, and restore a monarchy all at the same time! Is there any means that is not justified by the intelligence of the person who uses it?" (Buitenen, 1959, p. 217)

I

Science, we are often told, inhabits the domain of facts and not the domain of values. This is false. Those who know science also know, for example, that all explanations are not *valued* as scientific explanations, and all evidence is not of equal *value* in determining which of the two conflicting explanations one works with in the development of her theorizing. Judgment in science is justified on grounds that has its own standards or norms: there may be *good* grounds to accept a coherent set of evidences as evidence for or against a particular explanation, there may be *good* grounds to grant use of a recently developed vaccine in a public health system and, on the similar lines, there may be *good* grounds to reject *Vastu Shastra* as a '*science* of architecture' or astrology as a '*science* of stars and their effects on human lives' irrespective of the cultural-value it may have held. Science is valued not merely for its particular cultural import or for it predictive control of the natural events – it is valued for truth is of *value,* and science tracks truth. Those who question the 'tracking of truth' by science may still hope that it may add *value* to our lives as a *tool* of progress by controlling material-human-ills and by aiding technological innovations. In all events, scientific knowledge arguably is of *epistemic* value. [For the realist position see, for example, (Psillos, 1999); for an exposition of pragmatist philosophy in general see, for example, (Scheffler, 1974)]. Are values in science constituted by epistemic values alone? Or are ethical and moral values also constitutive of values in science? And is education in science therefore committed not only to the development of scientific knowledge among the students, but also to the development of *values* on which this knowledge and its attendant practices are justified: when students learn science, they learn knowledge and practice of science, they learn what justifies these knowledge claims and practices. But is that all? Or to learn science is to learn the *values* in science: to learn the norms or standards based on which only some justifications are *valued* as scientific? Is education in science only a question of fact, the domain of 'IS'? Is education in science, like education in general, also a question of value, the domain of 'OUGHT'? The purpose of this paper is to discuss the question of value in science education. Not the answer but the question, with the hope that if the question is raised, is well conceptualized and well understood, then the teachers and teacher educators will be well-placed to consider it further: let the *how* be contingent on the *what*; let the value *of* science be contingent on values *in* science.

I must note that, this paper is not an argument for the moral superiority of the student of science. Indeed, the paper assumes that an exemplary person of science or a person of excellence in science is not a super-human being – someone who embodies certain super-values. Values in science should not be grounded on anything other than the values constitutive of humanity in general (Korsgaard, 1986). It would therefore be wrongheaded for a science teacher to ask the questions like "can the virtues or character traits that are typical of those scientists who have made the most important or lasting contributions to knowledge be taught?" That will be putting the cart before the horse. The paper suggests that to think of values in science education is to reflect on the *question* of moral necessities required of the student of science. Education in general may share some of these moral requirements and in that sense there may be nothing particularly and uniquely scientific in these, but the question is: should these be necessary personal attributes or qualities of the student *qua* her being a student of science, and if they indeed are deemed necessary then should the teacher or a textbook simply assumes these to be present, or should it also explore the possibilities of contributing to the development of these attributes and qualities, virtues and values.

Also, the proposals and argument of this paper is not an argument from experience that seeks empirical evidence – the claim is not that "generally successful -- or should we say 'productive' – science students do mostly have certain moral-ethical qualities or are virtuous persons. The question that I raise here is not a question of an empirically-derived-values. What I'm asking is: should a student, *qua* a student of science, be a certain sort of student – a student of certain moral and epistemic standing; and, unless a science student develops these virtues and values – comes to embody these – her science education is incomplete. If a science educationist grants this, she may ask, for instance, if her students have the courage and commitment to "look the facts in the face" (Shapin, 2008, P. 49).

II

R S Peters -- a philosopher of education, working at the helm of mid twentieth century educational theorizing in the UK – would have asked: is it possible for a student to be educated and grow up to be a bad person -- bad by whatever standards of good and bad we subscribe to as long as we do subscribe to some standards? If we grant this possibility we are either mis-using or mis-understanding the term 'education', or we are simply admitting of a possibility of a failure of educational processes to educate a child into an educated person. On similar lines, is it possible for a student to be educated in *science* and grow up to be a salaried scientist doing *bad* science -- bad by the internal standards of science however we articulate these, as long as we do and seek commitment to these standards? Arguably, if we grant this possibility, we are either mis-understanding 'science' or simply admitting the possibility of a failure of educating the student in science. An educated person -- who may also have learned science during the course of her education -- is expected to have developed some understanding of the *value* of science (Nagel, 1959). On similar grounds, if a person -- during the course of rest of her education -- is educated in science, her *science* education should have been of some *value* in developing that person into an educated person. The question is: what is the contribution of science in the desirable development of a person *qua* person, not *qua* scientist or technician? In other words, is there a relationship between knowing science and being a good/virtuous person? "Can science make you good? … what is involved in the changing relationship between knowing about the world and knowing what is right?" (Shapin, Boston Review, 2015)

> [The] concept of an educated person is of someone who is capable of delighting in a variety of pursuits and projects for their own sake and whose pursuit of them and general conduct of his life is transformed by some degree of all round understanding and sensitivity. Pursuing the practical is not necessarily a disqualification for being educated; for the practical need not be pursued under a purely instrumental aspect. This does not mean, of course, that an educated man is oblivious to the instrumental value of pursuits—e.g. of science. It means only that he does not view them purely under this aspect. Neither does it mean that he has no specialized knowledge; it only means that he is not just a narrow-minded specialist. (Peters, 1977, p. 8)

What is the aim of science education? Could we conceptualize it in terms of the following questions: Is it aimed at the student's learning to do science? Coming to know science – develop scientific understanding? Become and be a woman/man of science – person of science – scientific person – person that has the outlook of science – a person of scientific temper? Someone who understands the development of science and develops into a person of science? Of course, a person of science may not be a moral/ethical authority (Shapin, 2008) but should a student of science learn to have a certain moral/ethical standing as a part of her science learning?

We can also approach the question of value in science education from the other end, not from the end of values that science should contribute in the desirable development of the student *qua* person, but in terms of the values that a student is required to build to know and do science.

Historians and philosophers study the growth of scientific knowledge – how do we come to know the details and depths of the natural world with a certainty characteristic of science. Science educators could ask an analogous question – analogous but not identical: how do students learn science and develop the scientific understanding of the natural world with the authority characteristic of a scientist? The following commonsense seems to prevail in the domain of science education: scientists use scientific method to arrive at scientific knowledge. The students of science therefore have to master the scientific method – once they do it they not only learn science, but learn how to learn science: school science in some sense therefore has to mirror the practice scientific community. In other words, to learn science is to do activities that constitute the method of science, thus constructing scientific knowledge in the space of science classrooms and labs – or, in a romanticized version, out in the lap of nature itself! There may be better articulations of this commonsense narrative, but let's leave it for another occasion. The focus here is not on discussing student's "construction of scientific knowledge" by employment of the "scientific method". The focus of the present paper is not the process of science learning, but on the ethical-character of the learner: what values the science learner should have developed – *qua* a person of intellect and integrity -- to learn the facts and theories of science. What demands the learning of science makes on the learner *qua* person? Should a science teacher assume the virtues necessary to practice science as already present in the learner's personhood? Or are these rational and ethical virtues part of the formation of a science student?

To the extent that certain universal, domain general values are central to the theoretical and experimental activities and beliefs of science – ultimate values of truth, goodness and beauty (simplicity or elegance) – success in science education has to necessarily hinge on success in the broader domains of education in general, while at the same time contributing to it significantly in the Science's own terms.

Of course, the kind and character of knowledge-object (mathematical, historical, aesthetic, and practical) you pursue may or may not determine the kind of person you may become. But does the kind – or character-- of knowledge that one comes to learn have the potential to develop the general quality and character of the learner *qua* person? Indeed it is possibly the latter question that forms the part of a debate between advocates of liberal and vocational education. [The argument has been made to the effect that while some vocational studies may be liberating (computational mathematics), others may not (mastering the skill of e-typing). (Standish, 2003)] Or does the acquisition and development of knowledge of the natural world put certain demands on the being of a learner *qua* leaner, and hence has a potential to transform her character and conduct?

III

Scientific knowledge is valued for its objectivity. What maintains the objectivity of scientific knowledge: the access it affords us to aspects of the objective real world; or are the personal qualities of scientists and their moral/ethical integrity also a contributor in maintaining the objective certitude of scientific claims? Are there any "moral warrants [that] stand behind [the scientific authority's] claims to knowledge?" (Shapin, 2008, p. 6) Should there be a qualitative difference between the demands a teacher rightly puts on a *person* who knows science and that on the scientific *knowledge*?

Science education is bound to remain a poor contributor to the moral fabric of its students and society if science educators choose to remain oblivious to the relationship that obtains between the character of scientific knowledge, the character of how this knowledge is secured, and the character of a scientist as a pursuer of the scientific knowledge. Learning science is not merely following the "rules" and "procedures" of doing science. Can rule-following of scientific procedures replace the personal virtues in meeting the demands of "credibility and authority" in science? In fact, such a belief seems to have its origins in the developmental history of science: "from a sacred to a secular world, from trust-in-familiar-people to anonymous trust in impersonal standards and faceless institutions; from virtue to institutional control as a solution to problems of credibility and authority." (Shapin, 2008, p. 13)

One wonders if the present day science education has effectively – and to its own detriment – replaced intellectual virtues of an enlightenment scientist by civic virtues in the perusal of "recognition and success" in scientific profession? (Cf. ibid. Chapter 6):

> "Universalism, disinterestedness, anti-authoritarianism" are the virtues of a scientists that were thought to be necessary to produce objective knowledge, for only such knowledge could help us manipulate the natural word for benefits to build powerful technology and growing economy. But precisely these virtues make the efficient organization/industrialization and effective/productive control of the scientific workforce difficult (Shapin, 2008, pp. 15-16)

Do the science educationists today expect that their students learn to "speak Truth about Nature"? What are the norms and ethos of the scientific community that they are expected to internalise as a part of science education? (ibid., 22-23). Are they essential for someone to have understood the nature of scientific theorizing and scientific practice? This question will not arise if learning is meant to be successful problem solving – to be able to predict and control the course of events without much ado about the character and quality of knowledge of underlying causes of these events. But the natural philosophers of the era of so called "scientific revolution" did worry about this. In the face of "the personal and the contingent… the distorting effects of language, convention, interest, and personal bias [arbitrariness and idiosyncrasies]", what should be the foundations of the beliefs: beliefs that reflect the truth and reality of nature? Could a Method "discipline… the personal and the contingent"? Shapin (ibid. p.32) writes that:

> Faith in Method grew even as incompatible versions of what such a Method might be proliferated. Yet one key feature all early modern Methods had in common was a belief that their *principles* could be formalized, written down, transmitted with ease from one person to another, and implemented by each person so as to yield reliable knowledge. For Method to fulfill such expectations, it would have to be as unlike spontaneously varying and uncontrollable human nature as possible. It would have to be invariant and impersonal in its operation. (my emphasis)

The scientific method is thus expected to discipline the judgement of the natural philosopher of the time. But there is a danger in understanding this in purely procedural terms. Excellent science is possibly not an act of providence nor a fiefdom of the "gifted". But is learning science "a functional labour analogous to the mechanical making of sausages, the grinding of corn or the crushing of ore", do those that do science are expected to "produce thought, continuously, as a mill makes flour"? (Ronald Barthes about Einstein quoted in ibid. p.33)

The cognitive value of scientific knowledge cannot be grasped without understanding the "logic of scientific inquiry", and according to Nagel (Nagel, 1959), it is wrongly assumed that scientific inquiry "requires no power of creative imagination" and follows "fixed rules". But there "are no such rules … there are logical canons for testing claims to knowledge … Those canons are themselves the distilled residue of a long series of attempts to win reliable knowledge, and they may be modified and improved in the course of further inquiries". (ibid. p. 59) To learn science is therefore to have a "clear grasp of the *standards* that evidence for a conclusion must meet … the *nature* of the grounds upon which the belief is maintained to be true" (ibid. 60, my emphasis). Note that to learn science is not just to learn the evidence but the standards of evidence and the nature of grounds of scientific beliefs. But this is not all there is to it: indeed, in Nagel's view, the essence of "practice of scientific method is "critical temper", "constructive rationality" and "intellectual humility" (ibid., 61). All these are values, values that reside in the thought-and-actions of a virtuous person, and her being virtuous had to have been contingent on her being educated.

But why is it that we care for these qualities of character? Shouldn't the scientific community concentrate on reaping benefits of successful use of scientific beliefs to serve human ends for the progress of human societies? But the prior question is: what are the principles on which the activities and achievements of the community of science are evaluated? What are the grounds of organizing the practices of this community such that development of science is possible? And are these principles and grounds merely intellectual and practical – to be evaluated in terms of efficiency, usefulness and relevance; or are they subject to the norms of reason and morality, to the epistemic and ethical standards? And in fact it is the latter that should justify the success in the former. Nagel's views science community to be a "self-governing community of… free, tolerant, yet alertly critical inquirers… who conduct themselves in accordance with an unwritten but binding code". In absence of the code of conduct of science, there will be no evidence based "reasoned argument… no free exchange of ideas", it will be impossible to use "powers of imagination and insight", in short there will be no science. In science there is no impersonal "mechanism for discovering truth", institution of science has to counter individual "passions and vanities" by "the process of mutual criticism" and by maintaining the possibilities of dissent (ibid., 61-2).

Why there is a neglect of these qualities among the scientific community? Nagel's (1959) answer is that the enormous growth and differentiation of scientific knowledge forces experts to focus on their own narrow areas of work. They take it that to reflect on basic philosophical and methodological ideas and questions "is a luxury" for which they have little time. In fact "it is sometimes regard as symptomatic of declining research powers in scientific colleagues who do give such questions earnest attention." (ibid., 63)

Nagel therefore asserts that "primary if not exclusive emphasis in the teaching of science upon the development of specialized skills is a disservice to the student, to the future of both pure and applied science, and to the prospects of a liberal society … The prospects for a liberal society depend upon the teaching of science as part of a liberal education that is dominated neither by a narrow utilitarianism nor by a comparably myopic professionalism" (64-71). In contemporary times, we could also extend the Nagel's analysis to the myopic professionalism of science educationists.

On one level not being mechanical is understood to be conceptual, at another level to be moral and ethical – to understand and do science is to care for and categorically commit to norms of motivation, beliefs and actions of science.

IV

There is a distinction between being an authority to preach values and being a person of certain beliefs and conduct to protect values to maintain integrity of scientific thought and uprightness of practice. To learn science is to inculcate these moral-ethical values and to understand the development of scientific explanations, along with how the community weighs it on scientific evidence with the value of truth in view. Not that the character of science should replace or determine the character of a person – for example, scientific temper is not a pill to cure personal and social ethical ills. Science learning should contribute to the ethical and moral development of a person and her society, and the development of science *qua* science should be impossible in the absence of epistemic and ethical values. To learn science does not just believe scientific claims to use them to "solve new problems". To learn science is to value its epistemic and ethical achievements, to learn science is to learn the inherent values of science, it is to learn to act rationally and ethically and not merely intelligently. Chargaff puts it excellently: "I was taught that it is the task of the natural sciences to understand, not to outwit, nature. I am often told that this or that is an "educated guess"—a truly nasty expression. Much would be gained if the guessers were educated instead." (Chargaff, 1963, P. 196). The student of science not only knows science but she also has related "knowledge of the good": she is "sensitive and committed to the standards intrinsic to a pursuit" of science. To the values "which are constitutive of excellence" in science (Peters, 1977, P. 9) in other words, it is a diachronically *possible* for education in science to be "true to the child, true to life and true to science" (National Focus Group on Teaching of Science, 2006), but *only* if it is true to the truth and the internal standards of moral and ethical excellence in science.

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CHILDREN AS FILM MAKERS

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Schools largely draw upon written assessment focusing on language abilities of students. We wondered whether drawings that require other abilities can be used for assessment of students. Earlier research has attempted to connect children's drawings to their social abilities and intelligence. However, given the significance of drawings, their potential has not been adequately realized in school education. We focused on studying communication ability in children through the medium of visuals. The study emerged from a workshop in which we taught children to create their own animation films using stop motion technique. A group of eight students (studying in 4th and 5th grade) were taught how to use a smartphone for making an animated film. After learning the technique, students thought of a story and animated it by using snapshots of paper cut-out drawings. We observed that some students could communicate through film what they wanted to convey more successfully than others and this was largely because their stories had a clear narrative structure, with a beginning, middle. The results of this study align with larger educational research wherein drawings can be used as means for understanding visual communication in children, especially in the form of visual narratives. (Doherty-Sneddon, 1996; Cox, 2003).

Introduction

Schools are not just places where children acquire new abilities, but also places where students are evaluated for these acquired abilities. In recent years, with growing concerns over developing critical thinking, the focus has shifted from memorizing to developing overall intellectual capacities which include higher order thinking skills. Importance is also given to the development of motor and physical abilities in the form of drawing classes and physical education, while some schools or universities may emphasize courses on developing communication abilities. These communication abilities often refer to verbal communication. Thus, there is not much focus on developing visual communication abilities of students. According to Vygotsky, "*Drawing...is the primary form of creative activity in early childhood*" (Vygotsky, 2004). Drawing, however, is a neglected ability and is not highlighted in schools. Being able to communicate using visuals must be seen as a distinct ability, different from general verbal communication. The ability of visual communication may not 'only' be required by professionals who work in art and design industries but is required by any person who is trying to present some idea to an audience. If teachers could develop the ability of visual communication themselves, they can play an important role in creating visual experiences for their students, without relying upon ready-made audio-visual packages that may not be tailored to specific local context of a classroom. Moreover, it would be interesting to learn how students respond when given the task of telling a story through a visual medium like animation film making, that requires them to make drawings. In this study, we are interested in comparing the quality of visual communication among visual stories created by a group of children.

Literature

Existing research on the subject of drawings by children comes from two different domains. One domain is the study of children's drawing and its relationship with intellectual and social abilities of children. A separate domain is that of visual communication research. We looked at children's drawing related issues in both these sets of literature. Florence Goodenough (Jolly, 2010), proposed that drawings could be a measure of a child's intellectual abilities (Goodenough, 1926) and created the "Draw-a-man" test for measuring intellectual ability through analysis of drawings made by children (Schloss, 1969). Dale Harris extended this study and proposed that the quality of drawings could indicate the level of intellectual maturity attained by children at different stages of development (Harris, 1963). The Draw-a-man test has been extended later by other researchers for testing a person's emotional state and interpersonal adjustment (Short et al, 2011). Similar tests have also been used for evaluating clinical disorder in children (Ireton et al, 1971) and emotional disturbance through Draw-a-Story test (Silver, 1988).

Despite the large number of publications on the subject, the reliability and validity (Pringle, 1963) of Draw-a-person (DAP) test for assessing children's intelligence at all ages has not yet been established (Willock et al, 2011). However, there have been efforts to improve the definitions of scoring instructions for the raters in the DAP test to improve its capacity to predict intellectual abilities of children (Phillips, 1973). While these studies have tried to infer the mental state of a child through her drawings, our objective is different. In this study, our focus is on understanding how well children can communicate their story ideas through drawings. According to Anim (2012), drawings can be used as means for developing communication ability and self-expression in children.

Since communication with visuals is a subset of communication theory, most of the rules of communication theory are also valid for visual communication. The SMCR model of communication explains the process of communication in terms of four main factors (a) *Source*, (b) *Message,* (c) *Channel* and (d) *Receiver* (Mabulay, 1960). Here, *source* is the starting point of the *message* which can be a single individual or a group sending a *message* to a larger audience. The *message* is the content to be conveyed that is encoded via language. The *message* is selected specifically for an 'audience' by the '*source*' and is formed of some elements that arethe components that combine to form the *message*. The organization of the elements is the structure that affects the overall quality of communication of the *message*. An aspect of communication is the *channel* which is the medium through which the *message* moves from the *source* to the audience. There can be a *channel* of hearing, seeing, touch, taste or smell. In visual communication, the *channel* is mostly images and to some extent sound, to support the visuals. *Channels* are also seen as media such as, books, television, radio, newspaper, magazine and the digital medium. The final aspect of communication is the *receiver,* which comprises the audience of a *message* in general, and can at times be a person in one to one dialogue or it could be a large group of people. How the *message* is sent or received depends upon the attitudes, knowledge and social-cultural contexts of the *source* and the *receiver*. Communication is the link between the source and the receiver. For effective communication, there needs to be a match between the *source* and the *receiver* (Bettinghaus, 1960). It is this effectiveness of *message* communication between the *source* and the *receiver*, that we tried to assess in this exercise using children's drawing and animation.

Methodology

As identified in the SMCR model of communication, our objective was to assess how clearly the message was transmitted from *source* to *receiver* through the *channel* of an animation film made using hand drawn paper cut-outs. In order to break down the structure of the *message* to its constituent parts, we used elements of foreground and background in the picture as units of analysis. Foreground and background are the essential elements of a picture's composition (Watson, 2006). Professional artists and photographers use these elements to draw attention of the viewer to some aspects of the picture that are necessary to convey the *message* that the *source* wants to communicate to the *receiver.*

Source: The sources in our study were 14 students studying in 4th and 5th grade (8 to 10 years age). These boys (10) and girls (4) were part of a summer camp at the Homi Bhabha Centre for Science Education (HBCSE). Among the numerous activities that students were involved in, one activity involved making a stop-motion animation film. Students were taught the technique and then asked to form groups to make a film with this technology. To begin with, students had to think of a story and draw the main characters in the story and the background scenes of the story. The characters were then cut-out and each individual character was shot with a still camera of a smart phone. Every change in position of the character, was a still photo of the cut-out character.

All the still images were processed in an Android phone application called 'Stop Mo pro'. The application shows the preview of the still images running at 'x' frames per second (fps). For this exercise, we chose the frame speed of 16 fps. A total of 4 groups were formed, one child refused to be part of any group and he made the film independently. We could see the influence of popular stories in the selection of stories chosen by students to animate. Figure 1 shows the titles and snapshots of the films.

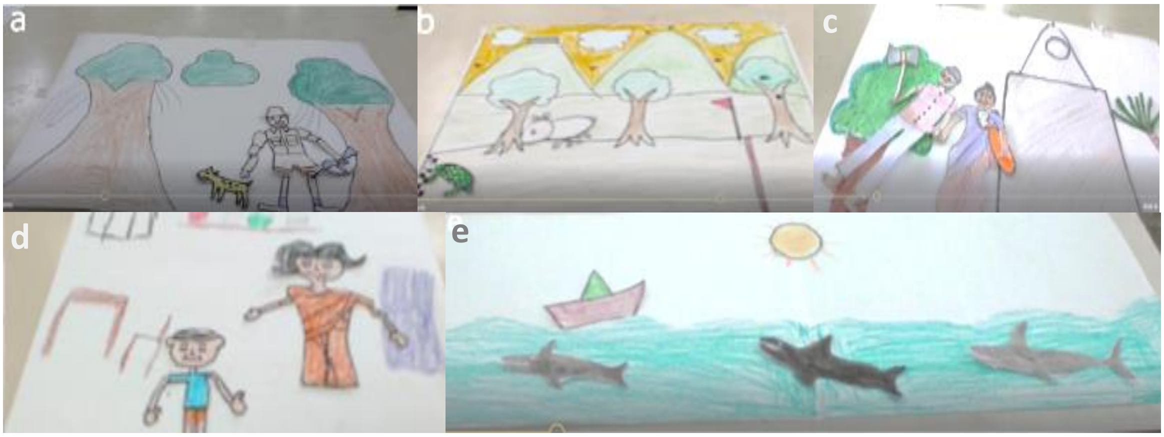

Figure 1: Films produced by children (a) Hunter, (b) Hare and the tortoise, (c) Jungle book, (d) Mother and child, (e) Sharks.

Message: The message consisted of a story that students had chosen or thought out to animate. The groups were free to animate an existing story or create a new story.

Channel: The medium which carried the message of story was a stop-motion animation film which the students made. The films were on an average 20 seconds in duration. When drawing for the story, students generally drew the main characters, the background scene and superimposed the characters in foreground over the background. They used the 'stop mo' application to take photographs of each frame and changed the position of the character frame by frame while taking still pictures of each frame. The application then processed the still frames to produce the illusion of motion and gave the final output in a movie format.

Receiver: Receivers were ten research scholars from HBCSE who volunteered to review the films. They were asked to see the films and answer few questions about the components and structure of the message that the films contained.

Framework for analysis

A questionnaire was used to check how the receivers perceived the message of the films and contained questions about the foreground and the background. For example, we checked whether receivers were able to identify the characters in the foreground and their relationship with each other, and if they were able to identify the background elements (forest, sea, house etc). Finally, we checked whether the receivers were able to identify the stories or describe the story they had viewed. We also checked whether there was any consistency among different receivers regarding their identification of the elements of the story. If different receivers identified different things, then the communication of the story was not effective, while consistency among responses of receivers meant the communication was clear and effective.

We assessed the quality of foreground and background drawing of the picture/film through the developmental stage theory of children's art. Children's drawing quality progresses through 5 stages of development (Roland, 2006). The first stage is called *scribbling.* In this stage the child only draws scribbles of circles and lines. The second stage is a *pre-schematic stage* where the child begins to depict objects through minimum lines. She does not draw how an object looks like but what she remembers about the object. The third stage is the *schematic* stage. Here the child begins to draw objects that resemble abstract form of reality. The fourth stage is a *transitional* stage where the drawings are closer to being realistic and the fifth stage is *realism* stage where the drawing resembles an actual three-dimensional object as it would appear in real life with light and shade (Salome & Moore, 2017). We assessed the drawings in foreground to find out the stage of development that the drawing represented. One point was given to each stage of development. This assessment of stage of development was done by the first author. It was also tested by showing one single drawing sample from the movie to the 10 receivers who had to identify the drawing. Their response was correlated with the quality of drawing score given by the author. Our objective was also to find out whether the most effectively communicated story also had the best quality of drawing.

Data

Table 1 presents the responses of the receivers to the 5 films made by the students. The vertical columns represent each film with its title. The horizontal rows contain data of questions that were gathered from *receiver*'s questionnaire (refer Table 2 for the list of the questions). For example, the *receivers* were supposed to identify the main characters present in the foreground. We have tabulated only those responses in which more than 4 *receivers* identified it similarly. We chose 4 because we wanted more than 50% of receivers to identify an element from the visual similarly. With reference to the film titled "Hunter", 8 receivers identified "hunter" as one of the main characters and only 4 people identified a dog as one of the main characters. This implies that the drawing of the "hunter" very clearly communicated who he is, but the drawing of the dog was not clear enough to be identified easily.

Questions for which no similar responses were evoked are marked with a cross (X) symbol. Row 8 contains the score about the developmental stage of drawing. A score of 1 for detail means only scribbling, 2 implies that a complete stick figure is drawn, 3 means a figure resembling some real object is drawn, 4 implies that a figure with clothes and color is drawn (a stage between symbolic and real drawing). Score 5 means that a realistic figure with light and shade color is drawn. Apart from the data about films, we also asked some receivers to identify one individual drawing element (rabbit/hare) from the hare and tortoise film.

	1 (hunter)	**2 (race)**	**3 (jungle book)**	**4 (mother-child)**	**5 (shark)**
(1)	Hunter (8), dog (4), deer (6)	Tortoise and Hare/rabbit (10)	Man, woman, child (6)	Boy, mother	Sharks and boat (7)
(2)	Hunter-prey (7)	Competitors (8)	Husband, wife, child (4)	Mother and son	X
(3)	Man, hunting animal (9)	Running race (10)	X	Boy going out of house (7)	Sharks playing in sea. Boat obstructing play. A shark topples the boat (8)
(4)	Outdoor (10)	Outdoor (10)	Outdoor and indoor (8)	Indoor (10)	Outdoor (10)
(5)	Forest (10), sky (4)	Sky (10), hills (10), birds (4)	House (9) Trees (7)	House (10), dining room (5), window (4)	Sea (10), sky (5), sun (5), boat (3)
(6)	Hunting in jungle (8)	Slow and steady wins (4), Running race (6) Overconfidence	X *Preserve trees (2)*	X	Play and movement of fish (3). Don't disturb the ecosystem/fish
(7)	*	Rabbit and tortoise story	X	X	X
	4	*3*	*4*	*3*	*4*

Table 1: Receivers' identification of foreground and background elements in the 5 films

Foreground: (1) Who are the main characters in the picture/film? (2) What is the relation between the characters? (3) What is the main action that the characters are doing?

Background

(4) Where is the action happening? (indoor/outdoor) (5) Based on your previous response, select all indoor and outdoor elements that you can identify in the picture. Add any other element that you see which are not given in the list.

(6) What do you think is the theme of the picture / film? (7) Can you recall any story on which the picture is based?

Table 2: Questions for the receivers

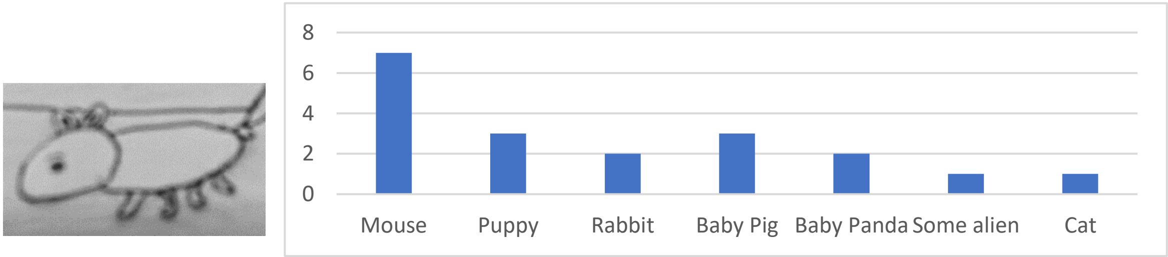

Figure 2: Number of viewers who identified the drawing as rabbit/hare or some other animal

Results

Only 2 groups (group 2 and 3) had made film about a story, while groups 1, 4 and 5 animated a sequence of events. The “jungle book” story had the highest score (4) in the quality of individual foreground drawing, but the film could not communicate clearly the main event of the story to the audience. In the “hare and tortoise” story, most receivers misunderstood the individual drawing of the rabbit as a mouse, but when shown in the film, all receivers identified it correctly as the hare and tortoise story. In the film “mother and child”, most people correctly identified many individual elements of the film, but the film could not communicate the main event in the story. Only those films that had a narrative structure with a beginning, middle and end could communicate their main theme to the audience, while those that did not have a narrative structure could not communicate their theme.

Discussion

Communication value of a drawing of /for a story does not depend upon quality of individual drawings. A story made with good quality individual drawing may fail to communicate the theme of the story. For example, in the case of “jungle book” story, even though the quality of individual drawing of father and mother is at 4^{th} stage of development, the receivers were still not able to identify the story of “jungle book” in the film. The reverse may be true as well. An individual drawing that is not of good quality may acquire a meaning if it is placed in a composition in relation to some other elements of drawing and action. All receivers could easily identify the story of “hare and the tortoise”, but most receivers when shown the drawing of a rabbit in isolation, could not identify it appropriately. The drawing is practically non-recognizable without its context and the presence of more elements in the drawing do not ensure that it will be communicated well to the audience.

Stories and events with a structure of beginning, middle and end were more easily identified by receivers than those events and stories that did not have this structure. In the “mother and child” story, receivers correctly identified the maximum number of objects in the background, yet they could not comprehend the main event. We found that it was not necessary that an existing popular story will inherently have a narrative structure. For example, the “jungle book” story did not have a narrative with beginning, middle and end, while the “shark” film, which was not based on any existing popular story, had a clear narrative structure.

Conclusion

Examinations in schools are mostly based on testing students’ written and verbal communication skills. Even if students are tested for specific subject matter knowledge like science, social science or mathematics, proficiency in any written language is a necessary requirement for students to present their subject matter knowledge. Because of this, students who may be able to answer some questions in their native language, may find it difficult to write the same answer in a second language like English (Aula, 2014). An alternative to written communication is visual communication. Some students may have the ability to communicate some ideas with a narrative structure through visual stories. We have seen that communicating messages through a visual story does not require acquiring proficiency in drawing. This becomes evident when students are asked to illustrate a story with a complex composition instead of drawing of a single element/object. We propose that the possibility of evaluating students’ communication and comprehension ability through visual storytelling can be assessed and improved. In the current and traditional educational evaluation, students are assessed based on their ability to answer some predefined questions. However, some students, or all, may have the capacity to articulate ideas using visuals.

The task of film making for communicating a story seemed to be motivating for all children to participate. We feel that while it may seem like a complex task in which the whole scene must be animated as compared to drawing a static scene, this complexity along with use of technology like smart phone and animation apps, appears to utilize multiple task performance abilities of children. The tasks involved are; thinking of a story, writing a script (optional), planning the various scenes of the film, planning the foreground and background action, planning and drawing the characters, thinking of logical flow of action and scenes, and dealing with the technical aspects of mobile application to render a video output. Having many activities would aid collaborating students who can devote their energy on any task of their liking. The final output would be a joint effort of a group of children. Motivated by the findings of this research, we ask a further question, can the ability of students to express their ideas on a topic in visual format, be used as an effective instrument for evaluating students’ understanding of concepts and ideas?

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MEASURING PRACTICES, CULTURAL CONTEXTS AND POWER RELATIONS: A STUDY IN RURAL BIHAR

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Mathematics is viewed as being neutral, value-free, and culture-free. The present study problematizes this conception of mathematics and tries bringing to the fore the power and identity issues in mathematics education research. The study, rooted in sociopolitical framework, aimed at studying traditional measuring practices and examining the embeddedness of complex power relations within these practices. The traditional system based on using pailis (measuring containers) was found to be closely associated with rural economies, especially women. Market interactions provided several opportunities to understand the interface between two systems – traditional and metric. The observations and discussions clearly pointed to gender, caste, and class hierarchies at work in unfolding of these interactions. The paper concludes by briefly discussing some possible implications for adult mathematics education programmes.

Introduction

Traditionally, mathematics has been viewed as a body of infallible, universal and objective truths, far removed from the affairs and values of humanity (Ernest, 1991), thus treating mathematical activity as highly abstract, formalized and decontextualized. This view of mathematics has, however, undergone a "Kuhnian revolution" challenging the infallibility of mathematics and acknowledging its socio-cultural character. Redefining mathematics as a fallible social construction; a coming to know, continually expanding field of human creation and invention provides a rationale as well as a foundation for 'inclusive' approaches to mathematics; wherein "the social contexts of the uses and practices of mathematics can no longer be legitimately pushed aside" (Ernest, 1991).

Studying mathematics in cultural contexts, first and foremost, requires researchers to critically examine and reflect upon the construct of 'culture'. From the literature based on exploring the mathematics of different groups in everyday or work contexts, it is possible to draw at least two views of culture. The first view, based on investigating the similarities and differences among diverse community practices (for example D'Ambrosio, 1985, Ascher, 1991), masks the relationship between culture, power and conflict, and hides the notions of subordination and domination. However, the construct needs to be 'politicized' (see Millroy, 1992, Knijnik, 1993). In the context of mathematics education research, this means going beyond simply describing the mathematical practices of particular groups to reflect on questions related to valorization, distribution and accessibility of different knowledge systems (Vithal & Skovsmose, 1997).

The present study, informed by the 'socio-political turn' in mathematics education research (Gutierrez, 2013), attempts at highlighting the interplay of power and identity, while uncovering the 'funds of knowledge' in marginalized communities. The study aimed at foregrounding the 'voices' of the subaltern groups in relation to their practices.

The settings, participants & methods

The study was conducted in two villages from Hayaghat block of Darbhanga (Bihar), namely, Chandanpatti and Pipraulia, and a village from Hanumannagar block, namely Thalwara. The three villages have a multi-caste population. Of the total 1369 households of Chandanpatti, majority are Muslim (from 'upper' and 'lower' castes), there are some Dalit or Scheduled Caste households as well. Pipraulia is a small village with 328 households, majority of them belonging to Brahmins and Dalits, and a small number of poor 'upper caste' Muslim families. Thalwara is a large village with 1572 households, comprising mainly of caste groups falling within other backward class (OBC) and SC categories. In all the three villages, agriculture is the primary source of livelihood, besides working as daily wage laborers and seasonal migrant workers (Census, 2011).

The research was based on elements of ethnographic techniques. During the field visits, the researchers tried to understand and learn from the people and about the practices they engaged in employing multiple methods—observation, informal and semi-structured interviews, and focus-group discussions. The observations and conversations aimed at developing a detailed and nuanced understanding of the local measuring practices, and traditional–standard interface during market interactions. Based on the observations and conversations on each day, the rhythms of the following days were planned.

Data analysis & Discussion

Local measuring practices around weights

Use of pailis by women in almost every household to measure agricultural produce reflected local measuring practices related to weights. A paili could be any container like an oil container, which was found to be most commonly used (as shown in the picture below). These are used to measure small amounts. Most pailis were 250 g measures, but they varied between 250 g and 1 kg (some also measured 5 kg). Nirantar (2007) documented similar observations in a study in two villages in Uttar Pradesh, wherein women's lives and economies were found to be closely associated with use of pailis (mostly 10 kg measures), and barajjas (1 kg measuring containers) made of brass, wood, or bamboo.

Since all grains (wheat, rice, pulses, etc.) have the common property of occupying space, these can be measured using volume, or capacity measures. Kula (1986), an economic historian, while documenting 'archaeology' of measurement practices worldwide, also found evidences of similar capacity measures being commonly used and referred to in terms of weight.

Detailed discussions with the women revealed the following information about pailis; some of which have also been discussed in Nirantar's (2007) study report:

- There is no 'one', or 'standard' paili used by all.
- Owing to the different densities of the grain being measured, how much a paili weighs depends on what grain is being measured. As a woman told us:

  हमरे पईली में मुँहे-मुंह अढ़ाई सौ ग्राम चावल अंटता है, मगर चना का दाल जादा अंटता है.

  [My paili when filled up to the brim weighs 250 g for rice, but will weigh more for chana].

- Another important aspect that needs to be carefully observed to determine the weight is the way paili has been filled (i.e. leveled or heaped). Associated with the practice is the use of an interesting, rich vocabulary, like referring to a heaped paili as *oop-taap* and a levelled one as *muhe-muh*.
- Pailis were extensively used in barter economies. Grain measured with pailis are sold at local kiraana shops and chakki owners in exchange of some household items, or money. Children could also be observed buying hawa-mithaai (candy floss), barf-malai (ice cream), etc. in lieu of the grain. In traditional village economies, pailis are also used in lending to and borrowing grains from other households.
- Since the shopkeeper deals in metric units, weight of the purchased grain is verified at home using pailis.
- Pailis are used at the time of cooking. Using them, women make estimates about the quantity of rice (say) to be cooked for a given number of people.

During the discussions, men denied using pailis, and mentioned dealing in metric units. Most women from financially better-off families irrespective of the caste pointed to the lessened use of pailis over the years. This pointed to gender and class bias in the use of pailis.

Observing these women engaging in a myriad of complex and sophisticated weaving, sewing and measuring practices contributed to a new evolved understanding of mathematics for both the authors, who have been trained over the years to see things through an 'academic' mathematical lens. For the second author, it meant a much deeper realization of identifying and valuing his mother's mathematical knowledge. At this point, Fasheh's (as quoted in Coben, O'Donoghue & FitzSimons, 2002) account of his mother's use of mathematics echoes in one's mind:

"My mother's sewing demonstrated another way of conceptualising and doing mathematics—another kind of knowledge, and its place in the world. The value of my mother's tradition, of her kind of

mathematical knowledge, while not intrinsically disempowering, however, was continually discredited by the world around her, by the culture of silence and cultural hegemony."

Market spaces: whose measure has got the power?

In the markets, the metric system is being followed. Markets, thus, come across as sites where traditional system confronts the 'standard' one. What needs to be explored at this stage is – how are the boundaries between the two systems negotiated?

Observations made in the market spaces further deepened our understanding of the 'power' dimension associated with different measuring practices. Some examples of market interactions are discussed below.

- Asmaa, a non-literate 'lower-caste' Muslim woman went to the shop carrying five and a half kilograms of wheat measured using her paili. When it was weighed on the scale, the shop-owner told her the grain weighed a little more than 5 kg, and offered the price of 5 kg pointing that grain is of poor quality. Asmaa took the amount given by the chakki owner and left. She did not question him even though the amount of grain he said he had measured was less than what she had weighed at home.
- Raani confidently told the researcher that her paili, when filled to the brim, contains 250 g of rice. When asked to verify the quantity of rice (1 kg) she had just bought from a local shop, it came out to be a little more than three levelled pailis. When it was pointed to her that it should have been four heaped up pailis, she said smilingly:

  हम ही से गलती हो गेले होगा. ऊ (बनिया) त बटखरा से तौल के द हई.

  [I would have committed a mistake. He had weighed using (standard) measures].

It does not require much imagination that, during these daily transactions, illiterate women were not very likely to be able to read the scales, and thus were often cheated. However, it is not that people are blind to see these dishonest and fraudulent practices, but were submitting to the practices in the wake of inequitable social structures. According to a Dalit woman in one of the villages:

बनिया त कम्मे पैसा द हई. मगर जरूरत त हमरे हई न, त ओतने में देना पड़ हई. ऊ त कह द हई कि देना हौऊ त दे न त न दे.

[The shopkeeper pays fewer amounts. But since we are needy, we have to settle for whatever he proposes. He would say if you agree (for the exchange), alright; else keep it to yourself].

Millers and shopkeepers are frequently observed to take advantage of their stronger monopolistic position, usually 'rounding off' the measures in their favor. The women from an incomparably weaker and multi-disadvantaged position are left with no option other than selling the grain. Also, as noted by Nirantar (2007), people acknowledged market to be an "upper-caste male space", and people depended on them for loan and employment, further complicating the relationship between the two. Clearly, the observations and discussions pointed to an embeddedness of the practices in gender, class, and caste inequities.

Measure, in that sense, ceases to be a neutral, pure convention, but gets manifested as a value – good or bad, fair or unfair. In Kula's (1986) words:

"The measure, therefore, is an instrument for influencing the market in a direction favorable to whoever is in the position of strength. And that party will be the social class which, at a particular point time, holds, or shares, or participates in power."

Another important observation that needs attention is the huge contrast in the confidence levels of women in the interactions demanding them to switch between the two systems. As Nirantar (2007) notes that:

"There was a high degree of precision in the use of traditional measures. As 'outsiders', it was interesting that precision was linked to the traditional system (read imprecise), whereas when it came to the standard system (read precise) women ended up approximating because of power."

The calculations in daily lives are mostly carried out by dividing into halves, and halving again to get quarters; and multiplying by continual doubling. Most women, unlike men, were found to have difficulty using decimal fractions. While women find it easier to relate to weights, like pauaa (250 g), aadha (500 g), and paunaa (750 g), very few of them could calculate the weights in between, like 450 g or 800 g, and ended up approximating and losing out on some amounts. Also, women get limited experiences of weighing, especially in metric units, and doing calculations involving bigger numbers, owing to their largely domesticated lives. During the harvesting season, men usually weigh the agricultural produce in quintals. According to a man in the village:

अनाज बहुत जादा हई न. औरत लोग तौले और गिने में गलती कर द हई.

(There is a huge amount of grain. Women commit mistakes in weighing and keeping the counts).

Women usually have experiences with weighing small amounts of grain using pailis or *baats* (in the case of women who work as vendors).

Women also cited some of the attempts they have made to resist the numerous metrological abuses by learning how to measure and keeping sale purchase records with the assistance of some educated women from well to do families where they worked as maids. Grain measured using the scales are sold as they go from household to another in the village, rather than being taken to millers or shop-owners. However, this notion of 'resistance' seems to be limiting in the sense that it does not fully prepare them to interrogate and subvert the power relations. Concerted efforts are required to move on "from fighting the abuse of privileges to attacking privilege as such" (Kula, 1986).

Measuring norms, transgressions, and the sacral character

Some of the women rationalized the fraudulent practices by mill owners and banias by leaving it to their conscience, believing that the transgressors would be punished by the God:

घट्टी तौले वाले का अल्लाह इन्साफ करि हई. जब जहन्नम में धकेला जई हई तब घट्टी तौले का मज़ा पता चली हई.

[Allah will do justice with those who weigh less. They will know the taste of their deeds when they will be thrown in the Hell.]

Since times immemorial, frequent, interesting, and symbolic references could be found highlighting the importance of just and fair measures. Beginning with the Biblical texts, and later Quranic verses, myriad references are being made to metrological norms, transgressions and offences, thus, providing measures a sacral character (Kula, 1986). Some of these verses have been cited in the box below.

Biblical quotes related to measurement

Leviticus 19: 35-36

You shall do no wrong in judgment, in measurement of weight, or capacity. 'You shall have just balances, just weights, a just ephah, and a just hin.

Deuteronomy 25:13-16

You shall not have in your bag differing weights, a large and a small. "You shall not have in your house differing measures, a large and a small."You shall have a full and just weight; you shall have a full and just measure, that your days may be prolonged in the land which the LORD your God gives you.

Amos 8: 4-6

Hear this, you who trample the needy, to do away with the humble of the land, saying, "When will the new moon be over, So that we may sell grain, And the sabbath, that we may open the wheat market, To make the bushel smaller and the shekel bigger, And to cheat with dishonest scales, So as to buy the helpless for money And the needy for a pair of sandals, And that we may sell the refuse of the wheat?"

(Source: bible.knowing-jesus.com)

Qura'nic verses related to measurement (Source: quran.com)
Surah Al-Isra 17:35 "And give full measure when you measure and weigh with an even balance. That is the best (way) and best in result". **Surah Ash-Shu'ara 26: 181-184** "Give full measure and do not be of those who cause loss. And weigh an even balance. And do not deprive people of their due and do not commit abuse on earth, spreading corruption. And fear He who created you and the former creation" (26:181-184). **Surah Ar-Rahman 55:7-9** "And the Heaven He raised and imposed the balance. That you not transgress within the balance. And establish weight in justice and do not make deficient the balance". **Surah Al-Mutaffifin 83:1-6** Woe to those who give less (than due). Who, when they take measure from people, take in full. But if they give by measure or by weight to them, they cause loss. Do they not think that they will be resurrected? For a tremendous Day. The Day when mankind will stand before the Lord of the worlds?"

We also observed an extensive nomenclature used in the communities relating to dishonest practices, in terms of deliberate distortion of instruments, adopting incorrect techniques of weighing, and rounding off readings in one's favor. People, while verifying the weights of the things purchased from local shops, can be often heard saying with discontentment "घट्टी तौला है". While negotiating with the grocers, people often make statements such as:

अगर डनटी मारिह त तुंही का ईमान जाई ह. येहीला हम तुंही के ईमान पर छोड़िय ह.

(If you weigh less, you will lose your faith/imaan. So, I leave it on your faith/imaan).

The phrases, like "kachcha tol" and "dandi maarna" refer to unfair measuring practices – keeping the people deprived of the 'exact' or 'true' measurement. Frequent references to the "imaan" of the trader/grocer highlight how the idea of 'just measures' gets transformed to a symbol of a 'just man', or 'man of integrity' (Kula, 1986).

Concluding remarks

The study brought about our first deep understanding of coexistence of different systems of knowledge; and their positive and negative valuations depending on the macro social structures in which they are situated. It calls for problematizing the very nature of mathematical knowledge as being neutral, culture-free, and value-free.

The research offers profound implications for adult mathematics education programmes as well as school mathematics. Mathematical knowledge is usually transmitted as a set of decontextualized concepts and skills; bereft of the needs and aspirations of the students, and socio-cultural, historical and political contexts. Drawing upon a deficit discourse, adults and children from particular groups are perceived as if they know nothing of the realm of mathematics, and thus ignoring their 'funds of knowledge'. However, since the accessibility to different systems of knowledge is determined by social hierarchies of caste, class, and gender, it would be simplistic to assume that any reform effort focused only on schools, and not linked to challenging the inequitable structures would be enough.

The study brings to fore the paradoxical relation between mathematics on one hand, and justice and fairness on the other (Bose & Kantha, 2014, Nirantar, 2007). While mathematics is being viewed as the discipline of power and tool for empowerment, acute disempowerment due to structural inequities prevents one from accessing or using the powerful mathematical ideas.

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TOWARDS DEVELOPMENT OF A SCALE BASED ON THE CONCEPT OF SCIENCE FIELD IN INDIAN CONTEXT

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The paper offers a critique of the concept of Science Capital (as used by Archer et al, 2015), based on Bourdieu's work and advances a new concept of Science Field to measure the overall impact of science education on individuals in terms of scientific temper and decision making based on scientific rationality. Two aspects of Science Capital (SC) are specifically critiqued. Firstly, SC views that the individuals use science education mainly in an instrumentalist, strategic sense, as a Card, for future gains. According to the authors, this undermines the individual as a self-reflexive learner who acts as a social agent in the family, school and society. Secondly, the family centered intergenerational transferability of SC is contested by pointing out that influences on the learner from peers, teachers, media and community are multiple and complex. By focusing on the structural influences that govern individuals' ability to access and use science education, the SC framework ignores the multiple ways in which science education enables individuals to develop scientific dispositions and to act in scientific ways. Science Field provides a new approach to study the complex ways in which science education shapes individual motivations, dispositions, behaviours and practices.

Introduction

As concerns about retreat of reasoning from public sphere (Raina, 2006), presence of pseudo-scientific attitude and scientific illiteracy in Indian society have deepened (Bhargava, 2007; Nanda, 2008), and participation rates in non-compulsory higher science education has remained low (Desiraju, 2008; Srivastava et al, 2012; Rautela & Chowdhury, 2016); considerable research efforts have been focused on finding out factors like scientific attitude and attitudes towards science (Rao, 2013) that play key roles in determining aspirations for opting science careers and contribution to knowledge production. Educators of science have long back recognised the importance of scientific attitude and its inclusion in science curriculum as a specific objective (Subbarayappa, 2013). Since the ideals of democracy rests on the level of literacy in society, and any ideal democracy embrace the scientifically literate public (Durant et al, 1992), the understanding and addressing the issues afflicting science education paradigm has invited many innovative exercises to bear on the problems.

One such conceptual lens is Science Capital (SC). SC is an analytical tool for examining differential patterns of aspiration and participation in science in relation to possession of science-related forms of social and cultural capital (Dewitt, 2016). Michael (2006) has argued that the possession of scientific knowledge and resources helps learners to translate it into increased social agency. Similarly, Claussen & Osborne (2013) have argued that science qualification commands a strategic value in education and the labour market. Archer et al (2015) have shown that families with higher level of SC promote their interests in science oriented market through in-family socialisation. They have shown that higher educational qualification of parents reciprocates the acquisition of SC among children. Archer et al (ibid) argue that the SC captures "the sum of total capital possessed by learners related with science and science related issues". In other words, this is the overall knowledge of science related education and also the knowledge of what and how to deal with this knowledge. Further, taking the analogy of *Card* game, they claim that the knowledge of science acts as a *Card* that student need for strategic purposes. They use it strategically for their own purposes.

Problems with the concept of SC

Although the concept of SC is a brilliant metaphor and a sociologically crafted concept, it undermines the very notion of the individual as a self-reflexive learner, and their place as a social actor in family, school, and in larger web of community. The underlying assumption that the concept of SC follows is what one has acquired as a member of family plays crucial and, in fact, determining role in opting the science related careers, and in making a choice to gain upward mobility in their personal careers. Beneath the obviousness of this concept, there is danger here. The danger is that by propagating the notion of transferability of SC from one generation to another, it vouches to restore the reproducibility character of education that believes that those who have higher SC can only have the privilege to gain higher access in science related careers. This is a crucial lapse in the estimation of individual learner's potential and their innate capability to learn, grow, and act in retrospect. In other words, the very premise of educational prospect of the learner having high growth-mindset is undermined in the conceptualisation of SC. This takes away the autonomous space enjoyed by learner which is personal but non-negotiable to the life of learner, as, it plays a crucial role in what learner strives to be and become in future.

The concept of SC refers the differential SC attainment of learner's life to the differences in parental qualification. From the point of view of scientific literacy, such an idea is un-educative and defeating, belying the very purposes of education that puts the nature of self prior to the structure. Freire (2004) in the same vein has argued that investment of education changes the consciousness of people and transforms them for lifelong learning. Freire believed that learners act according to their knowledge. As they gain new knowledge in the process of socialisation inside or outside the classroom, they change their act accordingly. Similarly, a student of science does use scientific knowledge to overcome social constraints, and finally esteem for what learners strive to become. Such a notion of science education in the context of increasing importance of science in the knowledge society has shown a way out to construct new theoretical schema and accompanied scale.

This paper by critically appreciating the concept of SC, looks beyond the process of formation of SC and puts forward the claims that: (a) the concept of SC lacks the deep sociological nuances and vividness, (b) it bases their references from a narrow understanding of leaning science i.e. possession of scientific knowledge to merely pass examinations, (c) it continues to creep the fear of career, and job prospects in market related psychosis among young minds, (d) oversimplifies the transferability of science related capital from one generation to next generation.

Thus, we argue that the concept of SC uses the very reductionist approach of learning science undermining the emancipatory vision of education. In the backdrop of these drawbacks, we envisage a new approach to study the overall impact of science education on an individual learner which measures various aspects such as knowledge of scientific methods and its procedures, learner's disposition and preferences towards science, their nature of behaviour and practices related to socio-scientific issues, and finally their affinity or allegiance with respect to science.

Positing the concept of Science Field

The concept of Science Field (SF) can be defined as, "individual learner's total sum of possession of knowledge, ideas, behaviours, habitus and disposition, and affinity to science in socio-scientific situations." In other words, the concept of SF captures where the learner of science stands in relation to knowledge and understanding of scientific methodology and what are their attitudes towards learning, doing and internalising scientific knowledge. As different items of measuring scientific literacy and attitudes towards science add together in the concept of SF, the broader picture of how science education is doing at individual level can be analyzed.

The space ordained by SF is open and contested for both problems as well as possibilities. On the one hand it retrieves the autonomous space enjoyed by an individual learner who prefers to act as a agent in society, who strives to navigate himself/herself in different situations in what Bourdieu has called *Social Field*, to carry out social transformation in society. On the other hand, SF recognises the socio-cultural and economic constraints plays an indeterminate role in influencing the life opportunities of individual learner. Hence, SF does depend and is influenced by many social variables like parental qualifications, their life opportunities, family income, concerns due to socio-educational models and awareness in a society. Even though individual try to internalise, and act according to new knowledge and consciousness that they gained from in or outside the classroom. However, the concept of SF assumes that individuals do position themselves in a way to make a strong move in an informed direction to transform themselves from being to becoming. Hence, SF is not only an autonomous space but is also dependent on the complex and heterogeneous society like ours. From science teaching pedagogical points of view knowing of individual's conception of knowledge of and about science is an important step toward an ideal teaching. By mapping the different components of science learning, the SF concept also highlights the *praxis* part of educational tasks.

SF is a theoretical construct designed to measure the different components of science education like knowledge of nature of science, scientific disposition, scientific preferences and behaviours, affinity with science etc. that inform how strong or weak is the learner's autonomy in reference to acting on what they believe in especially in science related issues? Since the strength of tie of an individual with science depends on knowing as well as being of science and doing science, the concept of SF reflects the chromatic picture of (a) possession of scientific knowledge, and (b) the knowledge of scientific methodology, and processes to be called *Having Science* (c) how scientific they are or want to become in life can be called *Being Science* and (d) do they prefer *doing science* i.e. do they follow scientific methodology, reasoning, and rationality? (e) and how they affiliate with science? In other words, how strong is learner's bond with science? It also shows the extent of importance the learner gives to science in their personal and public life and whether learners are willing to rise on occasion and stand up for science in public. This sub-aspect of SF is termed as *Science Recognition.*

Components of SF

Understanding of the nature of science

To begin with, nature of science (NOS) is a complicated and controversial theme in the science education community. It is seldom talked and taught but is the most important component of science education teaching (AAAS, 1989). In recent years, it has attracted worldwide attention due to recognition of importance of scientific literacy approach to science education at curricular level. The current emphasis of teaching NOS is based on the belief that teaching Whole Science (Allchin, 2017) in science curricula helps learners to understand scientific concepts better and also helps long term retention. According to educational psychology research (Buehl & Alexander, 2001) individual's beliefs about knowledge (epistemological beliefs) help them in better attainment and contextualisation of knowledge. Further, a constructivist approach to learning science also supports such findings (Cakir, 2008). That is, in order to better application of scientific knowledge, learners must firstly have knowledge of what science is, how scientific knowledge is formed, and how science and scientists work etc. NOS educates learners about the premises on which science is based. Epistemic learning of science is inevitable in the context of long term learning and contextual application of scientific knowledge (Wieman, 2006).

The continued increasing importance of science based knowledge and services in knowledge economy have increased the popularity of NOS teaching in school science. According to Holbrook (1993) UNESCO in association with International Association for Science Education in 2000+ vision document has recommended member countries to make "Scientific and Technological Literacy for All" as an important part of the science curriculum. However, there is no consensus on the definitive tenets of NOS. A common understanding can be found among science educators on teaching for classroom purposes. The consensual approach to pedagogical dimensions of teaching NOS can be found in Leaderman et al (2013).

Understanding methods and principles of science

Knowing the content of science without comprehending the methods and principles of science belies the very purpose of teaching of science and science education curriculum goals. This means that mere familiarity with the theories, hypothesis, and formulae of science without knowing about scientific methodology and scientific rationality doesn't serve the purposes of education in the long run. Such education is merely reduced to what Aikenhead (2006) has called the phenomenon of *pipeline production*. We know that the success of science lies in the adoption of methods and principles in scientific investigation and processes. Hence, what lies in the beauty of learning science is the learning of how to apply scientific knowledge. And, this necessitates the very learning of methods and principles of science. These include adoption of scientific processes like systematic observation, experimentation, types of scientific reasoning like inductive and deductive reasoning, scientific processes and other science related activities. How these are carried out by scientists is a matter of great importance to an ideal student of science. They must have such prior knowledge to follow, imbibe, and do various sorts of works like distinguishing science from pseudo-science in society and develop logical reasoning. At curricular level too, it should be emphasised to teach children to *act like scientist* rather than merely becoming a future scientist.

Scientific behaviours and practices

Scientific behaviours and practices are the outer manifestation of realm of affect, taste, and aversion of individual learners regarding science related issues in socio-scientific situations. Whether a learner of science acts as a key player in society interested in observing and submitting to scientific behaviours and prefers to follow the consequent practices is captured by this sub-aspect of SF. Scientific behaviours and practices grow from the scientific reasoning that individual learner usually adopt. For the purpose of understanding, it has been called *Doing Science*. Some of the examples of *Doing Science* are- every day engagements of student with science related issues, valuing science related issues in personal and public life, and acting as a scientist in society.

Scientific disposition and preferences

Scientific disposition and preference is a term used to represent the inward manifestations of the personal habitus of the individual learner. Bourdieu has famously dubbed it as *Habitus* of the individual. Here, it is appropriated to connote the internal reflection of the habitus. Disposition is a personality trait that is either built-in or develops over a period of time with incessant observation and due to influences like formal and informal learning, peer pressure, digital media etc. acting on the individual. It is the key component of formation of scientific attitude that shapes the attitudes and inclinations of the individual; and must therefore be exposed to scientific reasoning. To sum up, what scientific disposition and preferences refer is an individual learner's quality of what can be called being *a person of science*. For example, whether learners are interested in knowing the underlying causes, meanings, and reasons behind the given phenomenon? It is determined by what individual learner prefers to follow. Whether they follow intuitive reasoning or scientific reasoning or they can subscribe to social and conventional mores is one example of scientific disposition and preferences. It captures what learners are interested in or are they inquisitive enough to follow scientific practices in socio-scientific situations? It is the first but important step to adopt and internalise the scientific behaviours and practices in the personal life of the learner.

Science recognition

Science recognition is a term that captures how much freedom individual learner enjoys to engage with science especially when socio-scientific issues touch the public dimensions of science. In other words, science recognition explores the nature of bonding that an individual learner professes in connection, allegiance, and affinity to science. For example, how does learner enjoy (a) by being with scientific community (b) by standing for/with science in public (c) by investing time in science related public outreach engagement (d) by participating in science fair and workshops etc.? Does a student of science really enjoy and love busting anti-science myths in the public domain? These are examples of activities related to science captured by the term *science recognition*.

Discussion

The exponential expansion of science roles in all areas of life in the 21st century is beyond our expectations. It has mesmerised humanity and earned the character of a promethean figure in our runaway world. However, it is unfortunate that our science education curriculum has not geared up to meet the needs and requirements of future generations. National Curriculum Framework (NCF) Policy 2005 took a remarkable step in consultation and democratisation of curriculum development in science education. It has set a milestone by covering up wide ranging consultations to many stakeholders. As far as science education is concerned, NCF has recommended the adoption of a new approach to science textbook writing. Such an approach has made it mandatory to fulfil the criterion of following types of validity: Cognitive, Content, Process, Historical, Environmental, and Ethical (NCERT, 2005)

Teaching *about* science is conspicuously missing from science education textbooks in India (Rai, 2004; Sarukkai, 2012). The very absence of knowledge about various aspect of science like scientific values and ethics, different methodologies of science and evolution of science in society makes a student handcuffed to know how and what to do with scientific knowledge. A typical model that science education paradigm in our country follows is to give information to child about phenomenon 'x' so that s/he can successfully reproduce 'x' in examinations (NCERT 2006). Fromm (2013) quintessentially called it "having mode of knowledge" in which a person thinks that s/he has the knowledge just like the material possession. But having such mode of existence of knowledge and the accompanying system of assessment today ellipses *the inner mode of being* and evaluates the learner merely on the basis of memory. Such system of education works in the principle of factory line of production that does not take into account of creative intelligence, internalization of knowledge, abstraction and other human aspects of education.

In view of this, we see the necessity of an alternative and more facilitative conception of evaluation of formal education and academic development that fosters the learner's cognitive and socioemotional competence. However, at the moment, we focus on the competences and knowledge base which decide how people act, after their acquisition through formative school science education. Or, in a more plainly world, does science education push them to act more scientifically and, do they act reflexively in retrospect and enhance their engagement with science? Are students gaining enough knowledge about *grammar of science*? In a nutshell, are students of science becoming more competent to deal with socio-scientific issues arising in present-day knowledge society? The concept of SF helps explore such questions and the centrality of reflexivity in our educational tasks and goals of scientific knowledge attainment. As science has gained ground in our society today, it is important to pause and face the question of social utility of science education; ass Yager (1985) has tried to *redefine* (emphasis mine) science education at the science/ society interface. The concept of SF uses philosophical binoculars to explore beyond the conception of learning of science as merely *having science* presented in our current educational paradigm.

Further, the concept of SF withholds the premise that the autonomy of learner provides scaffold to learner to do the things they want to exercise in private, public and social realms of their lives. It negates any analogy of SC that individual learner uses science education as a *Card,* like a Card player uses in strategic situations. Taking notes of Habermas' (1985) understanding of individual's action that a person is more than a mere strategic player, the concept of SF claims that as an autonomous social agent and reflexive learner, s/he does not always act as a strategic player. They do have different roles and positions in a society, that make them act differently in different situations like they act out of affinity, love, emotion, political motive or empathy. In other words, science education learners may assert themselves as conscious, free-willed citizens who can either opt to act for either instrumental reasons or organic purposes. Hence, the right analogy for scientific knowledge for a learner of science education would be not *a Card,* as the concept of SC asks for, but rather *a pen* which a learner of science tends to enjoy more often, and would like to possess in their pockets to make use of.

Conclusion

The aim of conceptualisation of SF in the domain of sociology of science education is to draw a clearer picture of relationships between individual learner's acquisition of knowledge about science with doing science, being science and affinity with science. The concept of SF negates the SC hypothesis that aspirations in the field of science are contingent on mere parental qualifications in science related program and makes a plea to convince that acquisition of SC is a much more complex activity. Hence, the simplistic understanding of inter-generational transferability as happens in case of capitals like economic capital is not true in the context of science education. As the concept SC has its own contradictions, there is need to move beyond theoretical framework of SC (Kumar & Singh, 2017). The fact that just because an individual learner was not born in a family of high educational status it would be fallacious to assume that s/he has less scientific disposition and aspiration than other. Today, there is need to enjoy the autonomy of science education and not to compromise.

To capture how the learner puts the knowledge of scientific concepts, theories and laws into action is a formidable task. However, any attempt to understand the dynamics of how a student of science covert science baggage for practical purposes is a significant contribution in bridging the gap between theory and practice in sociology of science education literature and also contributes in disseminating scientific temper in a society. The concept of SF underlines that science education is very organic to our life processes and human civilisation, and as a social enterprise it is prerequisite to our knowledge economy. To reduce it to mere possession of scientific knowledge would be detrimental to the future of our children's education. Hence, the concept of SF vouches that (a) *Knowing of and about science* is as important as *knowing in content-matter of science*, and (b) Learning the craft of using of science as important as possessing scientific knowledge.

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CHILDREN'S FUNDS OF KNOWLEDGE, AND THE ROLE OF THE SCHOOL (AMONG OTHER SETTINGS), IN DEVELOPING 'SCIENCE-RELATED CAPABILITIES'

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The paper attempts to describe the funds of knowledge brought by middle school children while learning science in an informal setting. These play important roles in the development of 'science-related capabilities'. The conceptual framework draws from the model developed by Gokpinar and Reiss (2016), which synthesises key concepts: habitus, capital and field from Bourdieu (1977), and capabilities and functionings from Sen (1999). The framework focuses on the role of outside school factors in developing these capabilities and its conversion to 'science-related functionings'. This paper however, looks at a combination of within and outside-school factors, drawing from funds of knowledge. A case is outlined of a low-fee private school, in contributing to habitus and its conversion to capabilities. The conversion of capabilities to functionings will however need sustained engagements, in order to nurture children's long-term relationships with science.

Introduction and context

The term 'funds of knowledge' has been used to refer to knowledges within cultures and households which have been 'historically accumulated and culturally developed' (Moll et al, 1992). These could include 'values, ideas and beliefs for making sense of the world', as well as knowledge and skills associated with occupations and ways of living associated with different cultures and regions. For example: knowledge related to agricultural practices, mining, managing the household, folk medicine, recreational and ceremonial practices, etc. Acknowledging these would help teachers develop meaningful pedagogical practices in the classroom, and enable children to be more engaged with the learning of science at school. There have been previous studies in the Indian context looking at local and cultural knowledges and its inter-linkages with school knowledge (Sarangapani, 2003); (Natarajan et al, 1996). The empirical study from which this paper draws upon, was an informal science learning programme/ summer camp conducted at the Azim Premji University (APU), Bengaluru in April 2016. It consisted of twelve half-day sessions spread over the course of a month. About twenty middle school children (who had completed classes 6, 7 and 8) from one of our 'practicum' schools, came to a 'Learning Resource Centre' situated in one of the University buildings. They formed smaller groups based on their interests. Four facilitators handled smaller groups of children based on their academic and experiential backgrounds. I was the facilitator of a group of five girls working on the theme 'Plants, trees and insects'. The structure of learning experiences during the camp has been described in another paper (Mathai, 2017). Children with scaffolding from facilitators largely decided the trajectory of experiences during the camp. Broadly, they decided to observe and document various developmental stages of trees and plants on campus. They also observed the behaviour of insects which were found near to, or on the vegetation, and attempted to identify them with help from reference material and the facilitators. They made science artefacts which included scrap books and a children's magazine, comprising contributions from their observations as well as various art and craft work. They brought commonly available seeds from home, grew them, and tried to research their cultural uses, including food preparations from different parts of the country. This understanding was possible from conversations with elders in the family, as well as faculty and staff at APU from different regions of the country. On the final day of the camp, children made a local food preparation of *ragi mudhe*. Ragi was also a seed that they had grown during the camp. Throughout the period of the camp, I was interacting with children outside sessions too: travelling with them from school to university and back, engaging with conversations related to their everyday life, aspirations, recreational activities, etc. I was able to interact with some of their teachers and parents as well. This gave me a rich, nuanced experience with all children (not only those in the group I was facilitating), and helped me connect their life worlds with their science worlds.

I realized that children were continuously trying to merge their academic and everyday experiences. The informal science settings and expectations were quite different from that of school science, in not being centred on a fixed curriculum, multiplicity of settings and nature of projects, learning trajectories, and a fluid sense of time. They were also taking on new roles in the informal setting, and forming 'hybrid spaces', merging knowledges from formal and informal experiences with links to science in different ways (Mathai, 2017). The term 'hybrid spaces' draws from earlier work with disadvantaged children in both formal and informal settings, related to literacy, science learning, etc (Moje et al, 2004; Barton et al, 2008).

Funds of knowledge while engaging with science

Children were found to be drawing upon different funds of knowledge which came together in their learning of science. These have been depicted using a concept map in an earlier paper (Mathai, 2017). The two major categories of funds of knowledge consist of: that obtained from informal learning experiences and knowledge from school.

There were different funds of knowledge brought in by students from their informal experiences, including traditional knowledge from households in the form of cultural practices. Children were enculturated into these practices through conversations with elders. This included knowledge of commonly available seeds which would sprout 'surely and quickly' in little containers or pots (one of the activities during the summer camp), food preparation with these seeds and plants during festivals, changing usages and diets over a period of time, etc. Children were also deeply familiar with local trees and animals from personal experiences: playing with and eating the fruits of the local Gasa Gase (*Muntungia calabura*; Singapore cherry) tree, experiences of seeing snakes, such as pythons in the neighbourhood, etc. There was also constant bombardment of information from the media, films, television, etc. pertaining to aliens, portrayals of animals in movies such as Anaconda, etc. Another important source of knowledge from informal experiences was from visits to and interactions with science learning centres such as museums, planetariums, zoos, etc. Such settings may involve discussions with parents, relatives and siblings with interests in science. Different funds of knowledge were brought in from children's school experiences as well. The school helped them engage with concepts linked to science. Typically what came through from conversations with children were knowledge of conventions such as graphical representations, those associated with drawing diagrams; a smattering of terms, facts and processes associated with concepts, and names of well-known scientists. Science classroom experiences also led to beliefs regarding normative expectations of a good science student. Reproduction of the textbook and its content through memorization and recall is common practice. Other norms included conforming to teachers' and management's expectations such as, obtaining high marks in examinations, aspiring for careers which require taking science subjects at the higher secondary level, being quiet and obedient in class, etc. There were also rather homogenous perceptions among children about the nature of science. Doing experiments in the laboratory was considered by them to be an essential requirement, though not matched by experiences in school as mentioned above. From children's perceptions, science in an informal space required 'doing' in the form of projects, and associated activities.

Synthesising Bourdieu and Sen: Gokpinar and Reiss (2016)

While many of these observations have been reported in previous studies as well, what may be meaningful is to see how these funds of knowledge could translate into 'science-related capabilities' and further 'science-related functionings'. These two phrases draw from the theoretical model developed by Gokpinar and Reiss (2016), which link important concepts from the work of sociologist Pierre Bourdieu and economist Amartya Sen. The concepts of habitus, cultural and social capital, and field (Bourdieu, 1977), help theorise science-related capital: its formation and reproduction, and development into science-related capabilities. Sen's framework helps us understand how these capabilities are converted into science-related functionings among children (Sen, 1999). Bourdieu's 'habitus' refers to the individual, as a member of a social group or community, internalizing certain dispositions, values, beliefs and practices which are held by members of that community. It is first formed at home while socializing with members of the family and close acquaintances. It could lead to bias or actions which are reproduced among members, while also allowing mediation between an individual's agency and societal structures. Important associated concepts are those of capital and field. Capital consists of certain privileged assets that individuals possess, again by virtue of being part of a family, community or group. This could be social capital acquired through networks and groups one is part of, or whose support an individual is able to mobilise. It could be cultural capital, in terms of symbolic resources and knowledge from cultural practices that could be used to understand and navigate the world. Or it could just be economic capital. A third associated concept is that of 'field'. It refers to contextual attributes and systems which help to activate and actualize the potentialities of the habitus and the assets contributed by capital. Bourdieu's sociological theorisation could imply determinism in the ways individuals are privileged or disadvantaged in their engagements with the world, or in this case, their engagement with science learning. Hence, Sen's capability approach is liberatory, in describing how individuals are *capable* of being in the world. He describes different kinds of freedoms which advance an individual to achieve these "valuable states of being" or capabilities. To quote "Political freedoms (in the form of free speech and elections) help to promote economic security. Social opportunities (in the form of education and health facilities) facilitate economic participation. Economic facilities (in the form of opportunities for participation in trade and production) can help to generate personal abundance as well as public resources for social facilities. Freedoms of different kinds can strengthen one another." (Sen, 1999). Actual capabilities therefore, are dependent on different kinds of social arrangements, along with individual agency.

Gokpinar and Reiss merge Bourdieu's and Sen's theoretical frameworks to produce a new model, in the context of science education. They view habitus and capital as providing an important set of initial resources to a child engaging with science education. This could translate into favourable socio-economic status, cultural and ethnic factors which privilege science-related careers, and perhaps positive science attitudes among family members. They then meaningfully bring in links with Sen's capabilities approach, in describing how these initial assets need to be converted into 'science-related capabilities'. This would typically be made possible in a field, such as with experiences in out of school informal settings, meaningful conversations with members of the community, engagement with hobbies and activities with links to science, etc. While structures are important, individual agency is also significant in the conversion of initial resources to capabilities. Concepts of Bourdieu and Sen are therefore linked, making the framework richer. Finally, the capabilities need to be translated into appropriate 'science-related functionings', in being able to engage with science over a longer period of time, as with careers. The presence of role models in the family, community, class, caste, region or gender, allow for the imagination of functionings, and possible conversion from capabilities to functionings.

Role of the school in contributing to habitus and science-related capabilities

While this model presented a meaningful set of concepts to understand the complexities involved in helping a child transition from initial resources to possible functionings in science, it remained incomplete in the Indian context. Restricting the development of these critical attributes to outside school factors alone, seemed limited, pointing to the iniquitous relationship between science potential and science achievement. A different imagination, where a larger burden rests on the school seemed imperative. This is especially so, with the increasing number of high-fee private schools providing 'exclusive' education to children, who are already advantaged in terms of initial resources (habitus and capital) discussed earlier. In this context, the case of the low-fee private school from which most of the participants in this informal programme came from, could be meaningful. While the normative expectations from the school curriculum were limited, as mentioned earlier, the management felt the need to encourage children beyond their school worlds. All children came from a lower-socio-economic background, and out of the twenty children who were 'selected' by the school to come for the camp, fourteen were girls. While I noticed that pedagogic practices in the school were quite conventional: the teacher primarily reading from the science textbook, few activity-based sessions, etc., both teachers and children were clear that their school experiences were not sufficient. Quoting from my field notes[1]:

Over several short conversations with the secretary, I came to know that the school catered mostly to students from a lower socio-economic background. Students who were considered to be 'good' were given special attention by the management. They were always looking out to see which 'bright' students could be placed in or given opportunities... Considering that the 10th std. results were important for their image, they took special notice of students at the school-leaving stage. The secretary would make phone-calls to the children's homes, enquiring with the parents about their children's study hours; would even wake up some of the children at an appropriate early hour in the morning; have regular meetings with parents: more to educate them about school and curricular requirements so that they cooperate with the management whole-heartedly, etc. They were welcoming when we first discussed the idea of a summer camp in April, and were also glad to know that this camp was being held only for their students. However, when we handed out the consent forms which needed to be given to their parents, there was some selection that took place. Again, the school wished to project those who seemed to be interested in

[1] Extracts are from various field notes written during the camp in April 2016.

science, had engaged with science projects, and who had done well in school exams.

The school was also functional during vacation time with teachers coming in for various administrative and planning work, meetings with 10th std. students, etc. The children I interacted with came from four South Indian states, and had settled down in Bengaluru over many years. There was a shared understanding and a sense of community among them: contributing to their habitus. They stayed close-by, often meeting up outside school, and shared common local knowledge. A few incidents described in my field notes, would help in highlighting this:

Shared festivals: *There were some cultural elements I was introduced to during these morning conversations and bus trips from and back to the school. One such which was interesting, was the Hosa Road fair. Though I have witnessed this fair earlier, during the four years I spent living at Hosa Road, the description and excitement of the school children brought it alive for me in a new way. For one, I was quite surprised at myself for perceiving this whole affair as a one-off 'rural' event. The children were together in welcoming me for their fair, while describing some rituals that I had seen and could not understand. They described goddess Annamma, as the benevolent deity of Hosa Road, who granted all those assembled during the procession that was taken out, whatever wishes they had. If there was a wish that needed fulfilment, an important part of the ritual was throwing bananas at the goddess. If the banana managed to touch the head of the goddess, then there was a greater likelihood that the wish of the devotee would be granted. The fair was spread over three days in May a few days after the 'summer camp' was officially over. I did see Annamma lit up with lights, hoisted on a towering structure which was taken out for the procession, and also the associated festivities, fun rides, and toys which the children recounted fondly. The children also fondly spoke about fairs in other regions of Karnataka (Mandya, Chitradurga, etc.) which they have been part of…*

School-community linkages: *… One day I happened to hear a very focused-looking teacher on a bike asking the children if their parents had all collected their rations as per the Public Distribution System allowances. I was wondering why the teacher was asking this question. Ramya[2] told me that teachers would often enquire whether parents were able to collect them. Else the school would help by collecting provisions for the family, if the ration card was handed over to them…*

Shared excitements and discussions: *… On one of the mornings, there was a dead python in a nearby drain found by one of the observant children in the group. He quickly informed everyone and all children followed soon after. They were connecting this to giant creatures seen on television, in movies such as 'Anaconda', and school books, encyclopaedias, etc. later on, during our bus journey as well.*

Wearing non-stereotypical roles with pride*: … Karthik surprised me with his vivid interest in cooking and eating: he wore it quite proudly and kept mentioning it to me. He actively helps his mother in making sambar powder, by roasting the ingredients. He takes these ingredients to the mill and grinds them into a fine flour which they could use through the year. He was also careful to remind me that 'they' do not add hing/ asafoetida in their sambar powder. He also told me that he prepared tomato rice in the traditional vessel used for cooking rice in his friend's home for their family. Karthik was also quite happy with the ragi mudde preparation on the last day, though this was something eaten by all the children at their homes for dinner every day. While most of us (especially the four adults in the group*

[2] All names of children are pseudonyms.

who did not hail from Karnataka), were struggling to eat one, he quickly finished three and was also happy to pack the remaining food and take it home. He later mentioned on the last day, when I did interviews with the children, that he enjoyed the muddes more than usual since there is that special joy in cooking your own food!

While these are scattered anecdotes, they assume significance in bringing out the sense of community among the children, which the school (along with home) helped foster in ways beyond the classroom, and contributed to the habitus (internalised structures within the peer-group and spatial community), capital (informal networks which were made possible because of the relationship shared between the school and APU, and possibly other such institutions), and field (multiple sites within and outside the school leveraging different funds of knowledge with linkages to science learning).

Discussion: from initial resources to capabilities and functionings

It would be appropriate here, to discuss the different funds of knowledge which these children brought into their learning of science mentioned earlier. The school and informal science experiences were seen as being clearly different for most children from their reflections after the camp. The school curriculum and pedagogic practices seemed to primarily familiarize them with certain normative expectations of being a good science student. The informal learning experience helped the terms, facts and processes in the textbook come alive for students through hands-on activities, observations of trees and plants, free-flowing discussions with facilitators, minimal structure in organization of experiences, bringing in local, place-based, traditional and cultural knowledges, etc. Children appreciated the two large significant 'fields' in their engagement with science-related experiences: the school and the informal space. Qualitatively, one could observe that they were developing science-related capabilities: asking questions, connecting their meticulous observations to their experiences, grappling with finding patterns and making sense of them, etc. (Mathai, 2017). However, this further conversion from capabilities to science-related functionings remains unclear. In conversations with students, a month after the camp, it emerged that this conversion was likely to be weak. The only two children who were clear that they would like to pursue science-related careers were those with certain family characteristics and personal dispositions. Vikram, received a lot of support and encouragement from his father, who would help him in activities such as in fashioning a telescope with spare parts at home. He had also developed a sceptical disposition, and was articulate with his concerns during the camp, being part of a group called 'space research'. Vikram was constantly exhorting the facilitator of that group to address his questions related to 'aliens', and also to take up more hands-on activities. He was firm in expressing his unhappiness whenever the facilitator could not take up his concerns. Karthik, also mentioned earlier, was confident, seemed to be one of the few in the entire group who could speak well in English, was constantly bringing up humorous episodes to enliven conversation among peers, and also wore his interest in cooking, with pride. Though the school's contribution to habitus is clearly evident from the descriptions above, the role of the socio-cultural environment, particularly the home, in fostering a sceptical disposition, confidence, articulation, work ethic and meaningful conversation about science-related activities is evident. Also, for three of the girls: Shambhavi, Ramya and Priya, who were engaged with activities and were developing science-related capabilities, the absence of role models in the family and community seemed to have dampened their interest in pursuing science-related careers or even long term engagements with science. Their argument for not taking up science (despite the meaningful work they had done during the camp), was that it was difficult, required persistence, and that they had not known anybody in the family or community becoming a scientist.

In conclusion, the framework provided by Gokpinar and Reiss (2016) bringing together foundational concepts of Bourdieu and Sen was meaningful. However, the context being limited to outside school factors supported primarily by the home, reduced the richness, and suggested further widening of the iniquitous conditions related to schooling in our context. This is particularly with reference to habitus and capital: type of schooling and exclusivity related to class, and parental interest in science learning. The funds of knowledge brought by children into their engagements with science in the informal programme suggested otherwise. A case was made of a low-fee charging private school, which acknowledged its boundaries in dealing with the science curriculum, and fostered engagements with informal learning experiences. It provided initial resources (habitus) as well as significant contextual engagements outside school (field) in helping children develop and convert these into science-related capabilities. However, further conversion into science-related functionings is more complex, and will need continuous and long-term engagements, with efforts from the school, family, community, informal settings, messages from the media, etc. to foster children's long-term relationships with science, and science-related careers.

Acknowledgements

I wish to thank the school, all children who participated in the camp, and my co-facilitators. This study was funded by the Research Centre, Azim Premji University, Bengaluru.

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DESIGN AND TECHNOLOGY EDUCATION'S POTENTIAL TO ADDRESS DIVERSITY

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India harbors diverse socio-economic, regional, political, religious, linguistic, ethnic, caste and gender differences. Catering to this kind of diversity in Indian classrooms can pose a challenge to teachers, particularly when there are added dimensions of diverse learning styles, skill sets, self expression, subject interests and abilities. This paper reports observations from a two day Design and Technology (D&T) workshop with eight student participants, who were presented with a design challenge, set in real-world context. Students worked in two single sex groups, and engaged in exploring, drawing, planning and making of the product (solution) collaboratively. Further, through discussions, students evolved their own criteria to evaluate the product. The insights gained through these observations, though preliminary, shed some light on how D&T units can provide possibilities of inclusion in a diverse Indian classroom.

Introduction

India is synonymous with diversity, such is the variety of cultures that prevail here. With a population of over 120 crores, India is home to a myriad of religions, ethnicities, castes and languages, often leading to several sections of societies facing discrimination and marginalization. The plethora of diversities is reflected in Indian classrooms, and can be a challenge to teachers as students differ not only in their home contexts, but also in their learning styles, skill sets, self expression, subject interests and abilities. India's national educational policies and curriculum frameworks have acknowledged student diversity and call for providing an inclusive environment for all, thus attempting to address the variations in children's backgrounds, needs and interests. Despite initiatives at the policy level, there is a need for sustained efforts to address diversity at the classroom level as well. It is in this context that we explore the possibility of Design and Technology (D&T) education as an inclusive approach to teaching and learning.

Addressing diversity in classroom

Over the last few decades, addressing diversity has emerged as an important discourse in educational literature. Enslin & Hedge (2010) say, "*If diversity is 'the great issue of our time' inclusion is commonly regarded in public discourse and policy as a key solution to the injustices suffered by groups excluded from the mainstream of society"* (p. 385). Literature on addressing diversity in classrooms has spanned several areas. For one, it is now acknowledged that diverse students bring to school different learning strategies, languages and ways of knowing (Heath & Mangiola, 1991; Cleary & Peacock, 1998). Studies also deliberate about the crucial role of a teacher in identifying diversities and developing strategies that may effectively address these (Rahman et al., 2010; Wiseman, Cooner & Knight, 1999). In the Indian context, there are several recent studies; on how science, science education and diversity are inter-linked; aiming to understand how national policies are aligned with inclusion and diversity; emphasizing perspectives and practices around inclusive education (Kumar at al., 2010; Kumar 2014; Chunawala & Natarajan, 2012; See Science Education for Diversity Project, 2010-13).

Several advocates of culturally responsive teaching (Ladson-Billings, 1992) also suggest that a teacher can address the interests of their diverse students and help in skill building if they are aware of their students' backgrounds, their values, languages and literary practices (Abt-Perkins & Rosen, 2000). Dias (2004) in a comprehensive review of literature in the realm of addressing diversity and communication, discusses some strategies such as: *use of narrations or stories, introducing multiple expression modes, group work, participatory and active learning by removing the boundaries between life and educational processes, having a goal oriented activity, design and production of technical devices, linking formal and non-formal activities to bridge gaps between everyday personal life and the world of structures and institutions* (p. 129). In the current study, an attempt was made to map the features of the D&T unit used in the workshop, to Dias's recommendations of fostering an inclusive environment that values diversity of modes of expression and communication.

D&T education

D&T education is an interdisciplinary subject that involves planning, exploring, imagining, drawing and making, though not limited to this. It helps to hone quantitative reasoning, manual and procedural skills and technological knowledge. D&T also provides opportunities for one to make aesthetic, social and value judgments as well as evaluations. D&T does not have a marked place in the current Indian education curriculum albeit its 'integrated' nature (Buchanan, 1992), unlike countries like Australia, England and New Zealand. However, in the Indian context, one can see sporadic elements of D&T in subjects like art, craft, and Socially Useful Productive Work (SUPW), but this has largely been desultory in nature (Mehrotra, 2008). Even technology education, colloquially referred to as engineering discipline in India, is a stream that is offered after Grade 12. Several educationists advocate D&T education in school curriculum (Baynes, 2008; Owen-Jackson, 2002) to groom citizens to develop their knowledge, technical and interpersonal skills which are required to sustain in today's society.

In the area of D&T education, some literature has emphasized how D&T and inclusion go hand in hand. D&T can offer opportunities for developing students' cultural awareness and understanding of their place in the world (Howe et al., 2001). D&T tasks have often '*reflected the culture of the technological world the students and teachers inhabited'* and given scope to make explicit linkages across science, technology and society (Natarajan, 2007, p. 166). The 'language' of D&T encompasses a wide range of verbal (speaking, arguing, discussion, presentations) and non-verbal communication modes (gesturing, drawing, using symbols, making models), thus providing an inclusive space to support a variety of learning and expression (Natarajan, 2004). Thus the guiding question for the current study was to explore what kind of inclusive dimensions can a D&T unit provide in an Indian context? The objective of this exploratory study was to gather instances of "inclusive practices" during the implementation of the D&T unit.

Methodology

A two day D&T workshop was organized with eight students (4 males, 4 females) from Mumbai, in November 2015. A diverse sample was selected through convenience sampling. All students were between 11-13 years, and hence parental consent was sought before the workshop.

Students' profile: There were a total of 8 students, all from grade 9 except one. There were 4 females (PS, RS, PT, SM) and 4 males (SM, MD, AD, FA). The students were linguistically diverse (spoke Hindi, Marathi, English, Tamil), regionally diverse (families were from North India, Maharashtra, Tamil Nadu), came from different religious backgrounds (Hindu and Muslim), had differing likes and dislikes. Three students reported that they liked science, 1 disliked science, 2 disliked mathematics. All students had somewhat similar socio-economic backgrounds. All except FA studied in the same school run by a private trust that followed Maharashtra State Board syllabus. Both schools were English medium, and were located in suburban areas of Mumbai. PS did not attend day 2.

Relevant sessions of the workshop were video and audio recorded. Two non-participatory observers individually maintained notes. Audio clips were transcribed and videos were scanned for evidences of inclusive spaces and practices. For example, instances where; students brought in their own perspectives and experiences, students' participation during group work, students' participation in different tasks and their methods of individual and collective expression etc. The observations of the workshop are described and categorized using a collaboration and communication centred D&T education model (Choksi et al, 2006; Khunyakari, 2015), which has six components, namely, Motivation, Exploring design, Technical drawings, Planning, Making and Evaluating.

Observations from the workshop

Revisiting science topics

Initially, concepts of hot and cold objects, temperature, units of measurement, conversion between degree Celsius and degree Fahrenheit, good and bad conductors of heat were revised with students. These topics were related to the problem task, hence a quick recap of these science topics was carried out. Students were asked to think of examples from their every day life about hot and cold things. According to students, cold things included, ice-cream, ice, *falooda* (iced-drink), *zameen* (floor), cold drink, water, *tulsi* (plant), *centre fresh* (chewing gum), mint, air-conditioner, while examples of hot things, included fire, sun, beverages, water, cooking vessels, iron, desert region, volcano.

Motivation and investigation

Students were provided a context in the form of a story, for developing a product (solution) for a real-world problem: *Suppose you are going to your friend's house which is an hour away. It's a hot day and you have a bottle of chilled cold drink with you, which you have to keep chilled during the course of your journey. Design and make something that can keep a bottle of water cold for the longest possible time*. Most students said they had encountered similar situations in life. The science textbooks of

Maharashtra State Board has chapters on 'Transmission of heat' and 'Effects of heat (class 7)'; 'Reflection of light' and 'Metals and non-metals' (Class 8); 'Heat' (Class 9). Thus the problem presented to students was related to their school curriculum yet was something they had all encountered in their everyday lives.

Exploration of design

Students were asked to make groups. Of their own accord, they split to form two single sex groups. Each group was asked to collaboratively arrive at a sketch of the product that would 'solve' the problem effectively. The goal was clearly defined, as mentioned in the design brief story. Team A (girls) used a consensual approach to negotiate a solution and started to design their product, while team B (boys) initially did not work collaboratively, had some differences of opinion, but over time, negotiated into producing a single design for their product.

Technical drawings

Students had to put down their ideas on paper. Figure 1 presents the technical drawings of the groups. At the end of day 1, both groups were expected to produce their technical drawings, a list of materials they would need to make the product, and also indicate the quantity of material required for each part of the envisaged product they were going to make.

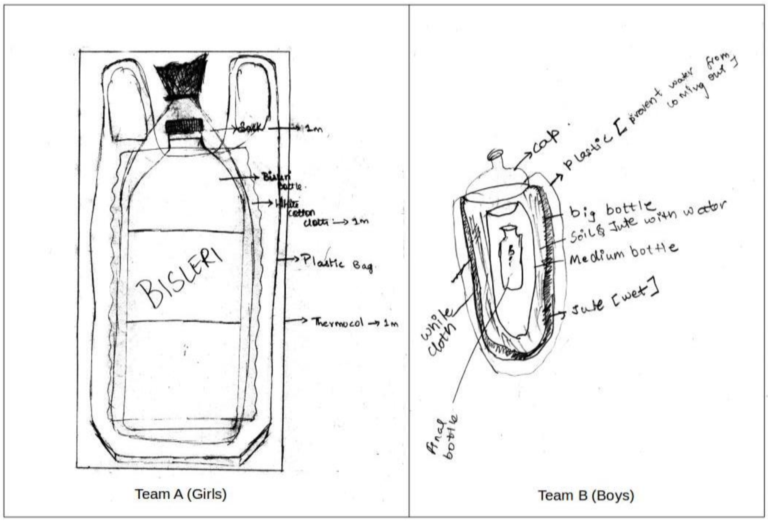

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Figure 1: Technical drawings of Team A-Girls (left) and Team B-Boys (right)

Planning

Planning involved the teams listing materials and tools required for making the product. Team A requested 12 items, which included jute, white cloth and thermocol. Their justifications for the choices were based on their past knowledge. For example, one girl (PR) mentioned that she had seen her grandmother wrapping cold water in a jute bag to keep it cold. Similarly, they recollected that they have seen ice-cream/cubes being stored in thermocol boxes. As for the white-cotton cloth, they said that in school science they have learnt that light-coloured surfaces reflect heat. Members of Team A used their earlier experiences from life and school to tackle the task. Initially, students asked for just enough material as per the dimensions of their design and did not account for buffer material required for sewing. On being questioned they realized that they have under-accounted the materials and needed to revise their dimensions. Team B also listed 12 items, however they did not explicitly state why they wanted the chosen materials, though they did specify decoration when asked about the colours and paints. Leaders implicitly emerged in both teams. In team B, the leader had a dominating character (SM) while in team A, the leader (RS) was more of a facilitator.

Making

On day 2, Team A divided the work amongst themselves systematically and used each person's strength to allot tasks. For example, one girl (PT) who was shy and often did not answer questions, took up tasks that involved cutting and stitching. The others (RS, PR; PS on day 1) were good at drawing and writing and hence they did the writing, tabulating and making of technical drawings etc. One of the girls (RS) emerged as the team leader, and took the initiative for the measurements and was more confident in answering questions. She also was not hesitant to guide her team mates when they had contradicting views. Team B worked more collaboratively on the second day as the 'product making' was time bound. It is also possible that they were inspired or challenged by their peers who were already ahead in terms of making their product. All members contributed, and involved themselves in different tasks and troubleshooting. The measurement and cutting for the bottle was mainly done by SM and MD while AD involved himself in the measuring, cutting and stitching of the jute bag. FA who was initially shy and did not speak much, took up the initiative of filtering and refining mud with MD.

Both groups were free to modify their original designs. Though the final product broadly conformed to their technical drawings, there were some changes incorporated. For example, team B added an extra material (silver foil) for their product while team A chose not to use a material (plastic cover) that they had originally asked for. Both teams sprinkled chilled water on their jute and cotton cloth layer. The girls (team A) did not spend much time in making their product attractive. On the contrary, the boys (team B) emphasized the product aesthetics. For example, they requested silver foil to make their product “attractive and shiny” (AD). When team B members (MD and AD) did the sewing for their 'cloth bag', they opted for coloured threads to make the product look more beautiful.

Evaluation

Once products were made, they were tested for their effectiveness. The results were tabulated and graphical representations were made to show temperature readings at 0 minutes and after 90 minutes, for each of the bottles. Teams had to 'test' their products against 5 bottles provided by us. Bottle 1 had no cover (control), bottle 2 had a woolen sock cover, bottle 3 and 4 were wrapped with bubble wrap and foam sheet respectively, and bottle 5 was a thermos flask. Bottle 6 was the team's 'test' bottle. In order to provide a non-competitive environment, teams were asked to test their product against bottles 1-5 and not against the other team's product. In general, it was observed that students had difficulty in understanding how to design and conduct an experiment to assess effectiveness of a product.

Despite care in conducting the measurements, errors crept in at various stages and there were problems in making graphs. The facilitators helped students with correcting their calculations and graphs. Evaluating the product required students to draw on their quantitative and graphicacy skills. The latter part of the evaluation required students to make judgments about their design as well as their peer's design, and reflect on the strengths and weaknesses of it. Students through discussions evolved criteria to assess and evaluate the products. These were: 1) usefulness (effectiveness of the product); 2) appearance (product should be attractive); 3) quantity of materials used (less materials, simpler, therefore better); 4) economic value (product should be low costing); 5) environment friendly (eco-friendly materials used); 6) replicability (potential for mass manufacture); and 7) compactness/portability (should fit in a bag, can be used while traveling).

Poor performance in any of the 7 categories was assigned 2 out of a possible 5 points, fair performance was assigned 4 points and good performance yielded 5 points. Thus the maximum total possible was 35 points, and minimum was 14 points. Both groups gave a formal presentation communicating the effectiveness of their product, and on the advantages and disadvantages of their design. The products of both teams ranked second in terms of effectiveness, with thermos (bottle 5) being the most effective. Presentations were followed by self and peer evaluation with a rubric that was developed using the above mentioned students' criteria. All the students evaluated their own as well as their peer group's product using the rubric. This exercise encouraged them to reflect upon their own design critically and compare it to the other design on a range of criteria. Interestingly, all members of team A (girls) gave higher points to the product of team B as compared to their own product; and all members of team B (boys) gave higher points to team A's product as compared to team A's points *to their own* product. When asked what they would have changed in their design to improve their product, team B said that they could have used clay from the river bed, it would have maintained the low temperature more. They also mentioned that their product was heavy as compared to the other team. Team A mentioned that they could have used thicker thermocol or outer material as they were concerned that the product might break during the journey, owing to its flimsy nature.

Discussion

This study draws from the Vygotskian theory of learning as a social process (1978). Participants in this workshop came from different cultural backgrounds, had different likes and dislikes, and brought their unique experiences to the task in hand. Despite differences, students were able to work collaboratively and communicate with each other, express their ideas and critique products. The D&T task used a story to contextualize an authentic design problem which was goal oriented (Murphy & Hennessey, 2001). The task called for multiple expression modes (Natarajan, 2004), involved group work (Johnson et al., 1981), and connected school science to everyday life (Aikenhead, 2006). Tasks were alloted by the group members (Dillenbourg et al., 1996) drawing on their individual strengths. At each stage, students were exposed to fresh perspectives emerging from different group members, thus requiring them to come to a consensus on aspects of design and making. Our observations indicate that when this heterogeneous group of students were faced with the design problem which had no single right answer, students sought multiple view points from all group members after which they had to justify the selection of one (of those solutions), and make decisions for which the entire group would collaboratively work on.

Communication was a key element in this activity; students were encouraged to speak in any language they were comfortable in, and they chose to speak in Hindi and English which most of them could understand. Students almost spontaneously discussed how they would tackle the 'cold challenge' posed to them and engaged in different modes of individual and collective expression. The task required students to make written records, that included tabulations, graphs and drawings; use verbal communication modes and gestures to express their ideas to the other group members as reported in earlier studies (Khunyakari, 2008; 2015; Mehrotra, 2008), thus catering to diverse learning styles and expressions. The products made by students were influenced by their home settings, their school learnings and their prior exposure to science, technology, skills and knowledge relevant to the D&T challenge (Ara, 2013). Further, the activity drew on their cognitive and motor skills. Students participated in a range of tasks like, drawing, making of the product which included stitching, cutting, measuring, sticking, filtering etc. This offered opportunities for students to hone a diverse span of motor skills versus just verbal skills, as in traditional classrooms.

The task also elicited students' own value systems and judgments. Students developed evaluation criteria and while doing so demonstrated their values on issues of economics, environment, sustainability and aesthetics. Evaluation '*allows the pupil to make a judgment or decision about the aspects of design as it develops, or to reflect on the strengths and weaknesses of the design once it has been completed*' (Kimbell et al, 2002, p. 208). The evaluation of self and peer performance is an essential aspect of D&T activities and generates in students an ability to be fair, unbiased, self critical and reflective (BCME, 2008) despite having objective and subjective criteria for evaluation. This aspect emerged when interestingly, all members of team A (girls) gave higher points to the product of team B as compared to their own product. Qualities such as being self-critical, reflective and unbiased are also important when dealing with diversity in the classroom or in the world. Lastly, the D&T task integrated various school subjects like arts, craft, science, mathematics, language and social studies. It is possible that the interdisciplinary nature of the design task engaged the students throughout the activity, despite several of them mentioning their lack of interest in sciences and mathematics, at the beginning of the workshop.

There seems to be a potential in using such D&T activities in Indian classrooms to address diversity as well as concepts from the school curriculum. If D&T modules tap into students' differential abilities, experiences, interests and strengths whilst catering to multiple learning styles, there is potential for such an activity to address diversity even in a seemingly homogeneous classroom. However, there can be logistical and practical barriers to implementing D&T units in Indian classrooms. Although no broad claims can be made based on this study, the observations do provide some insights into this under-researched area of D&T education, particularly in the Indian context. Further work is needed to develop more concrete D&T modules that are inclusive in nature.

Acknowledgements

The D&T workshop was conducted as part of the second author's internship at HBCSE. Thanks to all the participating students; to Durga Prasad, for facilitating the contact with students and their parents. Thanks to Disha Gupta and Pooja Sharma who helped with observations and video recording. Thanks to Shubhangi Bhide and Saurav Shome for their valuable inputs. The workshop details were initially presented at the *National Seminar on Education of Socially Disadvantaged Groups in India*, RIE, Bhopal, March, 2016.

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HEALTH LITERACY AMONG ADOLESCENTS IN A MARGINALIZED COMMUNITY IN INDIA

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Health literacy is a complex construct. Taking cognizance of the debates around health literacy, we examine what Critical Health Literacy (CHL) could mean for developing countries like India. We employ the CHL framework to analyze secondary students' understanding of health and its connection with hygiene, nutrition and poverty. Our interactions with 14 Grade 9 students who live next to the Deonar dumping ground reveal that most people in the community lack access to basic amenities like drinking water, hygienic toilets, and public healthcare system. While the students demonstrated sound understanding of the complex linkages between health and poverty, and the role of nutrition and hygiene in maintaining health, their scientific understanding of the diseases seemed inadequate. The findings suggest that there is a wide gap between what is taught and what is already known to these students through experience. In this paper, we argue that the CHL framework could be useful in designing instruction aimed at overcoming the gap.

Health as a context for critical scientific literacy

Critical scientific, technological and environmental literacy (CSL) is increasingly being recognized as an important goal of science education. Proponents of CSL advocate a radical overhauling of the mainstream science curriculum which has remained focused on teaching the products and processes of science (Bencze, & Carter, 2011; Cross & Price, 1999; Kyle, 1999; Roth & Désautels, 2002). "(I)nextricably linked with education for political literacy and with the ideology of education as social reconstruction" (Hodson, 2003, p. 660), the underlying objective of this approach is that students commit themselves to issues of social and environmental justice and take appropriate socio-political action on real world issues that have a scientific or technological dimension.

Pedretti & Nazir (2011) note that scholars who work along these lines follow two distinct approaches: 1) Place-based education, wherein the boundaries between schools and students' environments are permeable and students engage in locally relevant issues, and 2) Engagement with global social and environmental problems such as global warming and climate change.

Layrargues (2000) recommends that if students engage with locally relevant problems, it may enhance the possibilities of practical action and actual empowerment of the community. Following this recommendation, we explore the potential of health as a context for justice-centered science education for a community living close to a landfill by employing contextualized material that attempts to bring alive the problems that exist in the community.

Health literacy as an educational goal

Health is “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity” (WHO, 1995). It is both a personal as well as political matter, and has strong links with access to nutrition, hygienic environments and healthcare services.

Learning about what is health, how to become healthy, and factors that mitigate health, is a well-recognized educational goal. The understanding of what constitutes health literacy, however, has been changing (Nutbeam, 2008). For example, while many scholars identify critical appraisal of health-related information as the key indicator of health literacy, others emphasize more on the understanding of structural aspects of health i.e. the role of social, economic and political determinants of health. The report of Commission for Social Determinants of Health of WHO reads, “The scope of health literacy should be expanded to include the ability to access, understand, evaluate, and communicate information on the social determinants of health” (CSDH, 2008, p. 189).

Nutbeam (2000) proposes a more elaborate framework of understanding health literacy in terms of three levels. Level 1 involves *Functional* health literacy which is directed towards “improved knowledge of health risks and health services, and compliance with prescribed actions” (p. 265). Level 2 encompasses *Interactive* health literacy which aims to “improve personal capacity to act independently on knowledge, specifically to improving motivation and self-confidence to act on advice received” (p. 265). Level 3 involves *Critical* health literacy which entails “the communication of information and development of skills which investigate the political feasibility and organizational possibilities of various forms of action to address social, economic and environmental determinants of health” (p. 265).

Much work has been done on CHL since Nutbeam proposed the three levels of health literacy. In a review paper, Chinn (2011) identified three constituent domains of CHL: a) the critical analysis of information, b) an understanding of the social determinants of health, and c) engagement in collective action.

Health education in India

Recognizing the two-way relationship between education and health, health education has always received adequate attention in post-independent India. The Bhore committee that guided the program for development of health services in the country also underlined the importance of school-based health programs (NCERT, 2006, p. 3). A recent education reform document, the position paper on Health & Physical Education, re-emphasizes the need for an integrated and holistic understanding of health. It recognizes health as a multidimensional concept that is “shaped by biological, social, economic and cultural factors” (p.1). However, later in the document, when the specific objectives of health education are outlined, none of the objectives refer to the sociopolitical determinants of health (p. 12).

Research in health education in India is at a preliminary level. A notable study in the area is Mahajan & Chunawala's (1999) work on secondary students' understanding of eight dimensions of health (biological, nutritional, physical, environmental, social, psychological, addictive, and genetic) where they used a multiple choice questionnaire and found that students lacked understanding of nutrition, social and genetic factors that affect health.

Apart from the above study, there is very little published work available on health education research in India (Sharma, 2005), and much needs to be done to investigate the status of health education in the country in terms of the quality of instruction, the quality of educational resources available to students and teachers, and learners' views on health and related aspects. An attempt in this direction has been made in this study. The objective was to explore adolescents' experiences related to health and their understanding of health. Given the scale of health inequity in the country, we decided to focus on one particular locality in Mumbai, which besides being located next to a large waste dump, holds the least Human Development Index among all wards in the city.

Health of the M(East) ward

Mumbai is one of the most populated cities in the country divided into 24 wards for administrative purposes. The M(East) ward, mostly inhabited by Muslims and Dalits, is the most neglected ward in the city. The human development Index of the ward is a mere 0.05 (MCGM, 2009). Deonar dumping ground which is Asia's largest landfill is situated in this ward. The hygiene situation is poor for the community living in the close vicinity of the dumping ground. People in the community lack access to public hospitals, adequate toilet facilities, clean drinking water and nutritious food. In addition, an incinerator located in the middle of the area spews black smoke day and night. As a consequence, the health of the community is heavily compromised. The life expectancy at the time of birth in this ward is a mere 39.4 years (MCGM, 2009). Tuberculosis, diabetes, blood pressure, respiratory ailments, typhoid, diarrhea, reproductive health problems are some of the commonly reported diseases in the area (TISS, 2015). In comparison to other wards, the maternal mortality rate is high and so is the child mortality rate.

In the light of the above discussion regarding the status of the health of the M(East) ward, the following questions seemed worthwhile to ask from the point of view of the CHL framework:

1) How are the young adolescents of the M(East) ward placed with regard to their access to basic amenities that are essential for maintaining health?

2) What levels of health literacy do the adolescents of the M(East) ward manifest in less formal settings?

Study design

As discussed above, health literacy is a complex construct. Even the three levels (functional, interactive and critical) described by Nutbeam (2000) have several layers. We restricted the scope of the study to just three ideas that seemed crucial to make sense of health literacy levels among participant students: a) Understanding of various dimensions of health, b) Understanding of common diseases, symptoms, causes and practices of cure, and c) Understanding of social determinants of health.

In order to delve deeper into students' experiences and explore their understanding of health and related aspects, we followed a qualitative research design involving focus group discussions and written responses on two worksheets. Discussions around the worksheets, however, yielded richer data as students seemed more comfortable responding verbally.

We identified a state board secondary school in the locality. Students in the school belonged to lower socioeconomic strata and most of them worked in the day time to support their respective families. Depending on the willingness to participate in the study and their communication skills, fourteen students[1] (9 girls and 5 boys) from Grade 9 were selected for in-depth interactions on health and other related topics. These interactions were organized during school hours but in a separate room. To build rapport with young students, we spent the first three sessions on playing different games, sharing stories and familiarizing ourselves with each other. Participants found these and the subsequent interactions to be friendly, informal and less-threatening. All the sessions were video-recorded with the prior consent of the school management, participant students and their respective guardians.

To help structure the discussions, two worksheets and a set of vignettes describing the profile of people belonging to different socio-economic status were provided to the students. The questions in worksheet 1 were designed to help researchers understand nutritional, physical and health related practices of the participants, whether they were able to access basic amenities such as water and health care as well as what they perceived to be the diseases prevalent in their community. In worksheet 2, students were presented with a set of symptoms associated with a few commonly occurring diseases, following which they were asked to, ponder about the causes and possible cures.

Following this, there was a discussion around a set of questions on whether there were any possible connections between poverty and health and then students were presented with the vignettes. Chinn (2011) suggests that contextualized narrative descriptions might be useful in eliciting people's ideas of the link between social disadvantage and health. The vignettes helped trigger discussions on the complex linkages between health, poverty, nutrition, sanitation and access to healthcare facilities.

Findings & Discussion

Following the guiding questions, the findings have been organized into two parts: A) Students' experiences related to basic amenities affecting health, B) Level of health literacy among participant students.

A. Students' experiences related to basic amenities affecting health

Most people of the M(East) ward face severe problems related to drinking water, malnutrition among young children, inadequate healthcare facilities and poor hygiene in public toilets. These problems have been documented at length in the survey report of the TISS M-ward project. Data collected from the participant students in form of self-report also confirms the same.

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1 In this paper, the 9 girl participants have been referred as P_{G1}-P_{G9} and the 5 boy participants have been referred as P_{B1}-P_{B5}.

Access to drinking water

Two out of nine participants shared that they buy water on a daily basis. Three participants discussed problems with the unreliable municipality water connection in their homes. The other four participants did not seem to have concerns regarding the water connection in their homes. Those who buy water on a daily basis, pay INR 7 per gallon[2]. Other studies have also reported that very few houses have bore-well pumps installed in this locality. When asked about the quality of water, most students did not appear to have any issues. Practices of filtering water to make it potable are also not common in the community. One girl reported the use of alum to filter water. Another girl mentioned using a piece of cloth to filter water but none of them referred to boiling or other methods of treating water to make it potable.

Status of hygiene

All the students unanimously reported that people in the community rely more on public toilets where hygiene standards are low. The water supplied in these toilets is sometimes yellow in color and people have no choice but to pay and use the facility (INR 2 to INR 5 per visit). In some houses, men prefer to go to the dumping ground for defecation and young children use the open streets. The girls participating in the focus group discussion mentioned the discomfort that they face because of inadequate access to toilets and sub-standard hygiene.

Food and nutrition

We had asked participants to recall what they had consumed in their meals in the two days leading up to the workshop. All of them unanimously reported to starting their day with a cup of tea and biscuit (*khaari*). One girl mentioned that she had milk the night before. Others did not mention any intake of milk. The main protein sources in their diet that they reported were *dal*, chicken, mutton, and fish. All the participants reported to have eaten rice and *chapatis* in at least one of the meals on either day. However, their evening snacks comprised deep fried items like *samosas*, potato wafers and Chinese *bhel*. While their diet seemed to be protein-rich, it is difficult to say whether the quantity consumed was adequate especially because most of them appeared to be underweight.

Access to healthcare facilities

All participants reported that they consult private practitioners who charge INR 50 to 100 for a basic checkup. This reliance on private practitioners is not surprising given the complete absence of a public healthcare system. Four participants also mentioned that they believed in prayer as a mode of healing and visited sacred places like Haji Ali in case of a chronic illness. None of them mentioned visiting quacks/faith healers for treatment.

2 1 Imperial gallon = 4.55 Litres

B. Levels of health literacy among students of the M(East) ward

To determine the level of health literacy, we analyzed students' written responses to the questions given in the two worksheets and our semi-structured conversations with them.

Understanding of health

In a discussion on what health is and who would qualify as healthy, five different ideas were shared by participant students. Most students correlated being healthy with being chubby citing the example of *Bappi Lahri* (an overweight bollywood singer of 1980's). P_{B1} equated the idea of healthy with sturdiness. Another interpretation of healthy was that of being disease-free. P_{G5} expressed her opinion in this regard and argued that she is healthy because she does not fall sick frequently. Some students also associated the idea of mental peace and happiness with health. For instance, P_{G1} claimed about her friend to be healthy because she found her to be generally happy and smiling all the time. P_{B5} invoked the social aspects of health by mentioning drug abuse and alcohol consumption as some of the common malaises afflicting the locality.

These understandings of health have little overlap with the textbook understanding which builds up on the WHO definition of health. The discussion seems to suggest that even though most students had difficulty in articulating a technical definition of health, they did have an implicit understanding of various dimensions of health – personal, mental as well as social.

Understanding of common diseases, symptoms, causes and practices of cure

When asked to list the common diseases in their locality, seven out of nine students reported tuberculosis as one of the most common diseases. Four students reported common cold and fever as frequently observed diseases while typhoid and cancer were reported as common diseases by the remaining three. Some other diseases that were mentioned by the participants in this category include: dengue, malaria, and swine flu.

Some participants appeared to confuse diseases with their symptoms. For example, three students (P_{G1}, P_{B1} and P_{B2}) reported symptoms like headache, stomach-ache, cough, infection and jaundice as common diseases. Yet another student (P_{B5}) identified alcohol consumption, drug abuse and tobacco consumption as diseases which show that students' understandings are not bound by the rigid scientific framework.

AIDS, tuberculosis and diabetes were recognized as diseases that can get transferred from parents to children. A student P_{B5} pointed out that verbal abuse is also like a disease and "an uncivilized family environment where verbal abuses are common" is transmitted from parents to children.

In response to another question which intended to assess their understanding of diseases, symptoms, and preventive cure as discussed in their textbooks, the students did not provide scientifically correct responses. While seven out of nine participants matched tobacco and mouth cancer, none of the responses matched DOTS treatment with tuberculosis, or ELISA test with AIDS. Only one participant correctly matched ORS with diarrhea. Similarly, BCG vaccine was matched to tuberculosis only by one participant. Two correct responses matched polio with polio vaccine, and *Salmonella Typhi* bacteria with typhoid.

With regard to what causes these diseases, air pollution, poor hygienic conditions and low immunity were mentioned as the primary causes for most diseases. Most students related common cold with seasonal changes, headache with tension, cancer with tobacco and cigarette, and malaria and dengue with mosquitoes. However, some scientifically incorrect associations were also made by students. For example, one student wrote that tuberculosis is caused by overconsumption of alcohol; while another wrote that jaundice is caused when people eat a lot of chicken and fish, or drink milk.

In yet another exercise mentioned in worksheet 2, the students were asked to write about possible causes for symptoms of various diseases. Students' responses were of four kinds: a) medical reason, b) social environment, c) personal lifestyle, and d) cultural beliefs. An illustrative example of each kind is given in Table 1.

When discussing cures and remedies, participants mentioned several home remedies, particularly for common cold, vomiting, body ache, and watery eyes but for certain symptoms like blood in sputum or lose motions, they were sure that the patient should immediately consult a doctor. Most students also said that they don't rely solely on medicines and believed that prayer (duā) plays an important role in treatment. In another discussion, P_{B4} mentioned cultural practices involving black magic such as using a lemon to cure a long-term illness.

	Response types	**Symptom**	**What could be the reason?**	**Participants**
A	Medical reason	Blood in sputum	Tuberculosis	P_{G1}, P_{G2}, P_{G7}, P_{B5}
B	Social environment	Severe headache	Noisy environment, work tension	P_{G1}, P_{B1}, P_{B5}
C	Personal lifestyle	Repeated vomiting	Eating street food	P_{G1}, P_{G3}, P_{G4}, P_{G7}, P_{B1}, P_{B4}, P_{B5}
D	Culturally rooted beliefs	Mouth ulcers	Saying bad things to someone or wishing someone unwell	P_{B2}
			Eating others' leftover food	P_{G6}

Table 1: Students' written responses to the question related to symptoms and possible reasons

Social determinants of health

Students' understanding of the social determinants of health was explored through short vignettes. The discussions around these narratives revealed that students had reasonably good understanding of the interrelationship between health and poverty. This was operationalized in the vignettes as issues related to access to nutritious food, potable water, hygiene, and adequate healthcare facilities. Five short narratives of *Farida*, *Farukh, Sameer*, *Fayaz* and *Prakash* explored these themes. Students were asked to read these narratives and guess how healthy the children of the characters in these stories would be. There was no confusion among the participants about why the children of a poor person are less likely to be healthy. The role of nutrition, clean water, hygiene and access to healthcare system in maintaining the health was implicitly recognized by all the participants.

On the other hand, when asked to predict the average life expectancy of people in the M-ward and compare that with that of the more privileged areas in the city, some students said that the people of the M-ward would have a longer average life expectancy. They believed that since people in the community live in unhygienic conditions, they develop greater immunity and are generally sturdier. In support of their claim, some students also cited examples from their respective families which show that they did not have much idea of how these statistics are worked out as one cannot extrapolate the figures available for a few individuals of a population to arrive at the statistics for the whole population. Later on, when the government data on the average life expectancy of the M-ward was revealed to them, the presence of the incinerator in the middle of the community and issues of general hygiene were immediately pointed out as the primary reason for the shorter life expectancy.

The stories of *Rukhsar*, *Hamida*, *Shadab* and *Shafiq* explored the link between health and hygiene. While the character *Hamida* lived in a high class society where a waste collection and pickup system is in place and general hygiene is maintained by the community where she lives, *Rukhsar's* character lived in a small society where people throw waste outside their houses and let it rot for days. Many students were able to relate to *Rukhsar's* story and acknowledged the subtle connection between health and hygiene. *Shadab's* house was shown to be situated next to an open drain near a dumping ground which is also the harsh reality for many people of the M(East) ward. When engaging with this story, students easily recognized the fact that hygienic conditions are compromised for people like *Shadab* and therefore, their children are less likely to be healthy. *Shafiq's* story was about practices of open defecation and lack of hygiene in public toilets. P_{G5}, who read aloud this story, added that women in the community face a lot of health concerns because the water used in public toilets is not clean.

The students also acknowledged the close links between nutrition and health. *Ikra* and *Afsana's* stories revolved around this theme. While *Ikra's* character belonged to a rural context, *Afsana's* character belonged to a posh colony in a metropolitan city. What they had in common was the access to nutritious food. Students immediately identified the overlap in their contexts. In response to the worksheet questions as well, they showed familiarity with the relationship between nutrition and health.

Concluding remarks

The self-reports of the students of M(East) ward indicate that many of their families lacked access to basic amenities like adequate healthcare facilities, nutritious food, potable water, toilets as well as public hygiene which are crucial for people's health. These findings are aligned with reports of other independent organizations that have conducted surveys in the area (TISS, 2015). It is not difficult to understand why the health of the community members is severely compromised.

It is perhaps students' individual as well as community-level everyday struggle for basic amenities which informed their understanding of health. When presented with the vignettes, students seemed to have good understanding of the social determinants of health. They not only recognized the complex linkages between health and poverty, but also showed clarity in understanding how nutrition and hygiene were essential for health. However, technical understanding of the diseases in terms of their causes and remedies seemed lacking in the students. Their performance on technical questions worries us as the health education in India primarily focuses on information dissemination (Sharma, 2005). The students, on the other hand, did not show much familiarity with scientific terminology pertaining to the diseases given in the textbook which shows how disconnected the formal school curriculum is from the lives of these learners. There is a wide gap between what is taught in schools and what these students already know through everyday experience. We argue that this overemphasis on information in the curriculum is not helpful for students if we want them to develop a systemic understanding of health and take actions in order to ensure health for one and all.

In our interactions, students also brought references to alternative therapeutic practices that existed in the community which includes prayer, blessings, black magic and home remedies. These culturally-rooted beliefs and practices of cure need to be analyzed carefully and with some sensitivity towards their culture. Modern medicine provides one systematic framework to understand body, health and diseases but studies have shown that several indigenous medical systems (such as Ayurveda, Siddha and Unani) exist in the country where healthcare services are not accessible to all sections of the society. From a CHL perspective, if students from disadvantaged background are to be empowered to deal with health related matters, they need to develop skills to critically analyze these views and practices. Educators working with disadvantaged groups such as the community above has huge challenges ahead of them in terms of helping them critically assess these practices as well as integrate the necessary scientific knowledge to address the disease burdens affecting the community.

In developing countries like India, where structural constraints operate to make basic health care, access to clean drinking water and nutrition inaccessible to a large population of people, and where the state is withdrawing from investments in public health sector, the understanding of CHL also needs to be reinterpreted. We argue that if the educators are concerned about the health of disadvantaged groups and seek empowerment of the communities like the one mentioned above, instruction must be designed to incorporate following points:

- Recognizing health as a fundamental right of people
- Understanding of diseases, their symptoms, causes and possible treatments
- Understanding the complex relationship between health, sanitation, and nutrition
- Understanding health in relation to structural aspects such as gender, caste and class
- Understanding the nexus between the state and corporates in shaping healthcare services
- Ability to critically analyze cultural beliefs with regard to healthcare practices
- Commitment and preparation to take necessary actions to ensure adequate healthcare for everyone.

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WHO KNOWS AND DOES SCIENCE? - TEXTBOOK ANALYSIS OF KARNATAKA STATE BOARD SCIENCE TEXTBOOKS OF CLASSES 8 AND 9

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Science textbooks influence the students' understanding of science to some extent. Nature of Science drawing from philosophy, history and sociology has widened the understanding of science and the methods of science. Using the nature of science as a theoretical lens, this paper analyses the science textbooks of classes 8 and 9 published by Karnataka Textbook Society. Through this paper, it is argued that the epistemic authority according to these textbooks are the scientists and the 'Hindu' gurus. The textbooks' strong references to slokas, traditional pasts, and the sages seem to recreate the tradition and the truth. The farmers are presented as ignorant and illiterate who ought to be educated. Thus, this analysis highlights the need for alternative approaches to presenting science.

Introduction

Science education has been an important area of research for various reasons among educationists. Various studies have tried to elicit the meaning and purpose of science education and explored the approaches to teaching and learning of science. In India, researchers have studied how science and scientists are viewed, various approaches to science teaching, purposes of science education through philosophical, historical and sociological lenses. Classroom based studies that analyses the micro contexts, teacher's knowledge and identity, curriculum and pedagogy of school subjects through sociological lens are few and emerging in Indian context. Science classrooms become the context of the study for an important reason that women representation in science is poor. This study explored the experiences of girls in science classrooms and learning opportunities, later career choices and how these are shaped by various factors such as teachers' pedagogy, interactions among students and peers, school environment, curriculum and textbooks. These factors also seem to intersect with family choices and aspirations regarding girls' education. In this paper, the role of science textbooks in constructing certain ideas about science and scientists has been discussed. Karnataka State board science textbooks of classes 8 and 9 has been analysed for this purpose.

Theoretical framework

Science textbooks provide certain experiences to students, it conveys various scientific ideas, laws, phenomena and helps understand the concepts of science. The textbook and the teachers convey both implicit and explicit messages about science and scientists. In order to describe and analyse the science textbooks I have used nature of science (NOS) as a theoretical framework (Lederman, 1992;

Matthews, 1998; Elkana, 2000; Hodson, 2004). Of various issues that NOS would address I have discussed how history of science is presented in the text and the classrooms and how scientists are described in this paper.

Nature of science

The phrase 'nature of science' (Lederman, 1992; Matthews, 1998; Elkana, 2000; Hodson, 2004) is often used while referring to issues such as what science is, how it works, the epistemological and ontological foundations of science, how scientists operate as a social group and how society influences as well as reacts to scientific endeavors. The NOS has been described and debated widely (Lederman, 1992; Matthews, 1994; Woolnough, 1994; Elkana, 2000). According to Abd-El-Khalick et al (1998), scientific knowledge is tentative, subjective and product of human mind which is socially and culturally embedded. Science cannot explain everything; the explanations are highly possible or probable theories and not absolute truth or facts. Science can be done badly and its products can be misused and misrepresented. The notions of objectivity, universality, truth, neutrality, value-free and positivistic approach of science (Keller, 1985; Harding, 1986; Longino, 1989) have been critiqued by feminist science studies and thus, offering a better understanding of NOS. Kuhn's work, *The Structure of Scientific Revolutions* traced the history of science and provided better understanding of what scientific rationality involved and challenged the positivistic approach to science (Okasha, 2008).

The impressions on NOS are shaped by various factors such as school and teaching, media resources, societal views, cultural factors and so on. Though one cannot draw direct correlation between what is presented in the school and textbooks and students' understanding of NOS, the influence of teaching, teachers' beliefs of science, presentation of science in the curriculum and textbook to an extent influences students' views. Lederman (1992) indicates that the teacher's view of science necessarily translates into classroom practice and teacher's views of science and students' views are related.

The study

The study was done in a private English medium school recognized by the Karnataka state government in Bangalore, India. Bangalore is the capital of Karnataka. Ethnographic approach was taken to study the school and the participants for 6 months. It involved classroom observations, discussions and interviews with students, teachers and parents and analysis of science textbooks of classes 8 and 9. This study was carried out to understand how families, school, classroom, textbooks and teachers shape the experiences of learning of science and how these play a role in aspirations of students.

In this paper, I have only discussed how textbooks shape the learning experience and how science is presented by the textbooks and teachers. I have illustrated these through classroom observations and interaction between students and teachers, and textbook analysis. The textbook is the important resource in the classroom and teachers use it extensively. The teaching is primarily centered around the text and the textbooks seem to shape the classroom interaction. Thus, their analysis is important to understand how science is presented. Simultaneously I have presented the classroom interactions of biology and chemistry teachers of classes 8 and 9 to understand how the text is presented and interpreted by the teachers. There are two science teachers who teach classes 8 and 9 and both the teachers' views and classrooms interactions are discussed. Using the framework of NOS (Lederman, 1992), I have studied how and whether historical development of science is traced in the science lessons by the teachers and the textbook? The second aspect I have dealt with is the scientist. How are scientists described and presented in the text and by the teachers?

Layout of the textbooks

The Textbook Society, Karnataka has revised the text based on National Curriculum Framework (NCF, 2005) in 2012. There are about 24 and 27 chapters in class 8 and 9 textbooks respectively. The preface of the textbook says, 'The learner is encouraged to think, engage in activities, master skills and competencies…The new books are not examination oriented in their nature' (pg.ii). This statement and the actual content coverage appears contradictory. There is a vast range of concepts covered in the class 9 books, like linear and superficial expansion, elastic constant, meiotic and mitotic cell division, hydrogen bond, covalent bond, electromagnetic radiation, solar flares, and sunspots. Some of these concepts did not find a place in National Council for Education Research and Training (NCERT) curriculum[1]. Though the preface mentions that the new books are not examination oriented, the teachers were geared towards finishing the syllabus as it is vast. More than inquiry based projects, activities and experiments and helping to interpret evidence, the definitions, laws, equations and principles finds much place in the textbook.

The textbooks have various features. Each chapter outlines the objectives of the lesson at the beginning. The content is presented colourfully with images and diagrams. Some definitions and 'things to think about' are highlighted in boxes. There are activities and experiments mentioned in the lesson to be demonstrated by the teacher and/ or performed by the students. Following the lesson, there are questions and answers. Scientists who have contributed are also interspersed with their images and short biography. There are few stories and analogies and some attempts to contextualise the text. The textbook addresses the readers mostly in second-person (you) and sometimes in first-person.

Analysis

History or myth of science?

Many concepts in science are abstract in nature and their origins are as much a subject of scientific inquiry. Tracing the history of how concepts developed and how these were formulated, reformulated and how new paradigms have evolved over time could illuminate abstract ideas and make them more interesting (Mathews, 1994). History of science provides glimpses on how scientists worked, their failures and multiple attempts thus humanizing science and giving a sense that is a human pursuit. It presents science as human endeavor and not idealizing it as something 'out there'.

I analysed the textbook to see how and whether any mention of history/ historical evolution of science is introduced. It appears that mythology rather than history has taken precedence in the textbooks. The textbooks were revised in 2012 when Bharatiya Janata Party (BJP) was in power in Karnataka. The 'objectionable' content and 'blatant saffronisation' has been recognized by various experts, NGOs and

[1] The NCERT curriculum is revised based on NCF 2005. Following the revision, the concepts and no. of chapters to be taught have been cut down dramatically in the NCERT books. There are only 16 chapters in the textbook and concepts like linear and superficial expansion, elastic constant, meiotic and mitotic cell division, sun flares etc. which is discussed in class 9, in Karnataka State Board syllabus do not find a place even in NCERT class X syllabus.

textbook committees ("Revised Textbooks from 17-18", 2015). There are verses in Sanskrit and their explanation follows in English, while discussing various scientific concepts such as elastic properties of objects, properties of glass, blood circulation, human embryo, eclipse and on elliptical path of planets in class 9 book. For example,

> Regarding the elliptical path, Rigveda 1.164.2 says: (Verse in Sanskrit)
>
> *"Thrinabhi chakramajaramanarvam yathremaa vishwaa Bhuvanaani thasthuhu"*
>
> [The elliptical path through which all the celestial bodies move is imperishable and unslakened] (pg. 375, class 9, Science, Karnataka Textbook Society)

Almost every chapter has this kind of verse and explanation following it. The teachers did not make an attempt to read the verses or explain in their classes. These are usually skipped by the teachers. Several examples begin with 'our ancients' knew, or our 'Indian' sages knew about the concept in so and so B.C. The question is, did the idea of 'India' exist in B.C? Some of these verses and its origins as mentioned in the textbook are questionable. While discussing on the structure of the atom, there is reference to the 'Indian' sage named Kanada. Here the text not only had 'Indianised' but also glorified Kannada language. It says that '…material universe is made up of kana' (Kannada name of atom). The lesson 'Reproduction in Animals' (class 9 again), claims that Dronacharya was the first test-tube baby and 'we' had the knowledge of reproductive technologies since time immemorial. This is removed in the 2014 version of the textbook but found in 2013 version[2]. The purpose in this science text is not to discuss history of science to teach concepts better but to glorify 'our' ancient knowledge and claim that science was already in an advanced stage in the ancient times in India.

Class 8 books carry pictures of sages along with their contribution. There is two-page long description on agriculture in ancient India in the lesson titled 'Crop Management' drawing from Mahabharata, Rigveda and Arthasatra. It claims that Indians knew about water management, production of crops, types of land and so on. Following is an example of the classroom interaction while the teacher was discussing this lesson,

Example 1

Boy 1:	There is ancient history (refers to a page in the book)
Teacher:	You read boy, if you get any doubts, ask me. Go through, nothing is there, You know Charaka?
Students:	Yes ma'am
Teacher:	They are *our* ancient sage (*stress added*). Ok, read it

(Note- The boy refers to the text as history)

[2]Some students use 2013 version and the message is available to them. The report in the Hindu on 15th, June 2015, points to these errors (Dronacharya was the first test-tube baby) and it says while some changes have been made and will be reflected in the next academic year, a majority of the changes that are being sought will be reflected only in 2017-2018".

The teachers generally ignored these aspects while teaching the lesson and the assumption was that these are interesting stories to be read by students. They also felt that they do not know history of science much and how ideas were developed over time. As it is at the end of the lesson, it is not treated as part of the lesson. Usually the section highlighted in a 'box' with questions to think about or such stories are not given much importance in the classroom by the teachers. I asked the students about these verses and the stories from Mahabharata. The students felt that it is important to know them. One of them said, 'Our ancient gurus were wise and it is important for us to know about their work'. I asked students if they tried to read the stories in the text. Many of them said that they don't read the textbook at all and two or three mentioned that they read everything in the textbook and liked reading such stories. I could not get a sense if it is contributing to their understanding of concepts or process of science. From my analysis of the text it does not seem to lead to understanding of science as it does not describe the process of the science or evolution of concepts. It seems to only glorify that ancient gurus knew about these concepts and does not mention how they went about finding it. The verses or its translation are also difficult to read and does not explain the concepts.

Scientists know all

A particular narrative about who these scientists are, their contributions and how valuable their work is, are presented in the textbook and discussed by the teachers which I have described in this section.

The scientist as the white male from the western world is the general image in the text. There are 21 images of male scientists, in class 9 book and only two images of female scientists along with their husbands and their contribution. One is of Marie and Pierre Curie and another image is of Curie and Fredrick Joliot. It is important to note how female images are not presented alone and always along with their husband. Such a representation of women is restraining and normalized as women who are married and still achieving in science, in contrast to how male scientists' work is presented (Bhog, 2002). There is mention of C.V. Raman in the book but no image of him. These images and small biographical accounts of scientists are presented in box and highlighted. Class 8 book has images of 18 male scientists and no female scientist.

In the lesson on 'Crop Production' in class 8, there is a half page description on M.S. Swaminathan as the 'architect of green revolution'. The textbook describes his work and celebrates him and mentions that,

> *"Swaminathan set in motion fundamental changes in agricultural production in India that have put an end to India's age-old status as a nation on the brink of starvation…"* (pg.28, class 8, Science, Karnataka Textbook Society).

The teacher also referred to his work while teaching this lesson which I have described below, Example 2

Teacher:	Yes, sometime everything will not be good. You have heard?
Girl 1:	Farmers suicide, failure of rain
Teacher:	So green revolution has succeeded, but there is still hunger in India. What is undernourishment?
Boy 1:	They will not get proper food

Teacher: What is malnutrition? M. S. Swaminathan brought some changes. He is the father of green revolution; He also put an end to olden methods. He is a scientist and researcher.

The teacher seems to idealize the scientist as someone who put an end to olden methods (used by farmers) by bringing in new technologies that solved the problems of food production, malnutrition and hunger. Science is seen as the cure for all ills, and thus green revolution which cured the shortage of food problem in India and scientists as purists who bring about social change (Nandy, 1988) without problematizing the effects it brought on the ecology. The teacher while continuing the lesson mentioned that M.S. Swaminathan has worked to make policy changes such as Right to Food Act. The general awe that people hold for scientists makes them imagine that he contributed to Right to Food Act and that they generally 'do' good to people and the nation without critically analyzing the effects of green revolution. The personal dispositions of scientists are overidealised and eulogized by the textbooks and the teachers (Rampal, 1992).

As the scientists are praised, the farmers are often referred to someone as illiterate who learnt from these scientists. Here are few examples,

Example 3 (while teaching a lesson on 'Food Production', class 8)

Teacher: Do you know cross pollination? You have heard bio-technology? Have you? Ok, leave it. (Explains hybridization). Also, there was AIR (All India Radio) that time in olden days. It played important role in educating farmers. These steps increased food yield. They will be ignorant, 90% of them are illiterate. So, they were educated through this program. What to sow etc. This was broadcasted in AIR. So, there was increase of yield of wheat and rice.

In another instance,

Example 4 (while teaching a lesson on 'Chemicals in our Daily Life', class 9)

Teacher: Farmers give the soil for lab testing, we go for testing… *he* prescribes for blood test (stress added). Where do you go? To market?

Students: No ma'am, to lab

Teacher: So similarly, in lab, soil is tested. They test the soil, the soil is deficient or not, then they advise farmers, in the form of quantity, how much? There are natural or organic fertilizers, we have to go for artificial fertilizer. It relates to how we use tablets and overdose as doctors prescribe. So, farmers are also *educated* on how much fertilizers etc. (stress added) have you seen advertisement in TV? There is farmer's helpline. There is one story in this book. Read it. Fertilizers help in better growth.

The teacher mentioned twice that fertilizers are better than organic manures without considering the debates. In both the examples above, there is acknowledgement and recognition of scientists' work and the knowledge and work of farmers are disregarded. The teachers mentioned that farmers need to be 'educated' as they are illiterate. There is another kind of contrast that emerges in this text. Though it disregards the knowledge of farmers, the farmers of ancient India are celebrated. The work of scientists is followed by a description of ancient ‘Indian’ farming techniques. The textbook claims,

> The so-called “Persian wheel” used for drawing water from wells was first developed in northern India, prior to invasions by Turks (pg. 282, class 8, Science, Karnataka Textbook Society)

There is an assumption and a narrative constructed that ancient ‘Indians’ and scientists knew everything.

Discussion

In the name of history, ancient culture and myths are revoked in various chapter. There is hardly any representation of women scientists in the text. There is construction of particular truth, universality and objectivity without questioning and situating science in the context of the learner.

The truth constructed in the textbooks is the truth of the scientist and the truth of the ancient ‘Indian’ sages. There is a conflation of science with religion and particularly Hindu ‘rishis’ as bearers of knowledge. The contribution of Islamic scholars in the area of mathematics and astronomy are not referred to. The epistemic authority according to the textbook are the scientists and the ‘Hindu’ gurus.

The scientific knowledge is located in antiquity in the premodern era and in seamless continuity with Indian cultural heritage. The presence of mythical information is problematic because it leaves no room for verification or examination. It is easy to accept and difficult to resist such facts (Keller, 1985). Myth and science are at polar ends in terms of how knowledge is validated. The examples presented clearly indicate how using science as a medium to discuss the Hindu values and beliefs and mythical texts might create a dissonance among the learners. Though it is important to discuss the culture, Indian context, contributions of the Indians to science, it is important to present the information which is authentic and verified.

These books often imply that it is male, urban, upper caste and class who could produce and validate scientific knowledge. The rural farmers are often referred to as illiterate and ignorant and someone who are to be ‘educated’ by the urban scientists. The farmers are portrayed as mere consumers of modern agricultural techniques and the scientists as the producers of scientific knowledge. Such stereotypes permeate the class. One of the purposes of teaching science is to be rational, but many assumptions are unquestioned and accepted by both teachers and students.

Considering the above critique of the textbooks, it is important that textbook writers and teachers are helped to reflect and examine their own notions of science. The alternative approaches to presenting science need to be discussed and this might help students in better understanding of science and question the stereotypical views of science and scientists. There is lot of scope for discussion on NOS, limits of science, gender and science, history of science and interlinkages between science and society in the textbooks. Science education can provide a sense of agency and cultural capital and empower learners if the real value of science learning is established among students and teachers (Claussen & Osborne, 2013). In order to do so, the sociological, historical and philosophical perspectives of science need to be presented to students. Through the textbooks, aspects on ethics, worldviews, historical trajectories need to be presented in science education today.

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SCIENCE FOR CHILDREN: SURVEY OF TAMIL PRINTED BOOKS (1820 -1857)

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Publication of popular science books in Tamil for both pedagogic and pleasure of reading began with the institution of Madras School Book Society in 1857 under the patronage of the East India Company. After the first war of Indian independence (Sepoy Mutiny), the proclamation of Queen in 1857 extinguished the sovereignty enjoyed by the East India Company. A survey of the printed popular science books in Tamil during this period reveals the strategy adopted to 'domesticate' modern science in the cultural cosmos of the 'native' society by the European authors and their Indian collaborators. While most of the books were translations, abridged versions and adapted versions of English works published in England, and versions produced in Bengal, the rhetorical tools of catechism/dialogue from the European writing tradition were supplemented with the 'Uppanyasam/Pozhipurai' (Discourse/elaborations) rhetorical narrative styles prevalent in the Tamil cultural space. These tools enabled the twin motives of the European missionaries, namely their endeavour for 'mental' and 'moral' improvement of the natives as well as gain legitimacy as Pundits (erudite scholars) in the eyes of the Tamil literati and furthered the domestication of the modern science. Part of the larger project of understanding the contours of the domestication and appropriation of the modern science during the colonial Tamil region, this paper looks at how the European missionaries, at the dawn of colonialism, attempted to re-present modern science to Tamil region.

Introduction

From times immemorial, children had access to oral tales; composed, perhaps, not to be read but to be heard. Many of these tales, such as Aesop's Fables or Panchathantra, are animal tales with pointed morals. If one has to accept Gillian Adams' (1986) argument, "*an imaginative literature which may or may not have been originally composed for younger children or directed at them, but which was considered particularly suitable for them and to which they were regularly exposed*", then indeed it is possible to trace children's literature to even before the industrial revolution and emergence of modern society, and consider all the literature that were used by children as 'children's literature', then arguably earliest surviving literature belongs to Sumerians. Sumerian clay tablets, surviving from the period of the Third Ur Dynasty c.1000 BCE, excavated from possible school sites (edubba), indicate five categories of narratives: exercises for writing practice, the lullaby, proverbs and fables, stories of schoolboys' lives, and dialogues or debates.

Nonetheless, it was the 1820s-1900s, influenced by the Romantic Movement which idealized childhood that led to a greater interest in children and marked the emergence of the proper genre of 'children's literature.' It is during this period that authors and illustrators, in particular, European, began to turn their talents towards children and their books. Just as Ian Watt's (2001) influential account of the emergence of novel connects it with the growth of the middle class in the 18th century, it has been argued that one has to make a distinction between modern children's literature (post 18th century) in print and the literature to which children were regularly exposed to in the ancient times. In this sense, children's literature, and therefore, science for children is intimately connected with the advent of capitalism and modern society (Ariès, 1978; Morgenstern, 2001)

During the medieval period, copying of the texts was supported by the wealthy, and institutions such as seminary or mutt. However, the printed books need a market. Authors, publishers, and market became the network that sustained books in print. The rise of the middle class along with the industrial society, who could patronage print by purchasing books provided the necessary impetus for the print culture to take root in colonial India (see Dharwadker, 1997). Print also opened up new ways of composing texts, for example, prose presupposes writing. Although illustrations adorned early calligraphed texts, printing enabled the evolution of novel ways of organizing information and presentation. Tables, charts, illustrated diagrams, cartoons, and many other visual forms could be incorporated into the printed text. This, in turn, influenced the styles of writing, and new genres, such as novels emerged.

By late 18th century, sciences had become a part of the ‘public culture' in Europe, and during the early 19th century, there was a movement to extend children's education surpassing basic literacy and pedantic morals (Aileen Fyfe, 2008). Going beyond the staple fantasies, adventure stories, school stories, and girl-tales, science became a part of children's literature by the early 19th century in Europe and books began to appear in the homes of the growing middle class (Secord, 2014). Parley's Magazine for Children & Youth, a twice a month magazine published from Boston since 1833, emphasized on geography, travel, natural history, and simple technology, along with Biblical stories. In fact, it is said that Michael Faraday became interested in chemistry by reading Jane Marcet's 'Conversations on Chemistry' (1806). Adams, co-discoverer of Neptune, is said to have been initiated to astronomy by the book on heavenly bodies written by Mary Sommerville that was gifted to him in a school competition. The publication of about 30-40 books such as Samuel Parke's 'Chemical Catechism' which were being published in the early decades of the 19th century rose to about 90% by the middle of the century indicating a growing market and interest.

In colonial Tamil region, as most of the authors were European missionaries, it is natural that the early popular science publications in Tamil were influenced by the trends in Europe, in particular, England. Many of the early works in Tamil were translations, abridged versions or modelled on the influential works published in English. This paper surveys the publications during the early part of the 19th century documenting the early attempts by the missionaries to introduce science through the print medium. In particular, the narrative styles adopted by them to not only ‘educate the native,' but to 'convert them as well.'

Printing in Tamil region

Printing and publication arrived in India along with the European missionaries and traders. Scholars concur that a Tamil work named Doctrina Christam in Coolegio Do Saluador published at Cochin in 1578 is the earliest work in any Indian language to be printed from Indian soil, although Cartilha or Christian catechism, transliterated and printed in Tamil script at Lisbon in 1554 predates it. Nevertheless, the early printing efforts were sporadic and minuscule. Danish missionary, Bartholomew Zlegenbalg, established a printing press at Tranqubar in Tamil Nadu and forged Tamil types in 1713.

He printed tracts and small publications, albeit of religious nature, in Tamil. The publications were well received and relished by both Christian, and non-Christian natives. But the working of the printing press abated for want of paper and proper workmen and by early 19th century had to be closed.

However, by the early 19th century, East India Company was firmly established in south India, many missionary seminaries came up and to meet their demands, printing presses were established in Madras and few other missionary out-posts. A printing press captured from the French at Pondicherry was brought to Madras in 1761 and lodged with Rev Fabricius' Society for the promotion of Christian knowledge. Subsequently known as the Vepery Mission Press, it printed large volumes of Christian literature and educational works in 'native' languages for many years. During the late 18th century, a printing press was established under the superintendence of Fr. Andrew Bell, chaplain at Fort St. George. Male Asylum at Egmore, a government-supported foster home for orphaned boys was under his charge. Fr. Andrew Bell made the orphan boys go through ordinary schooling as well as training in various trades. Some were trained in the printing trade and the boys trained out of this institution were employed at such offices as Madras Courier, Madras Gazette, Egmore Press, and Government press at Egmore. With the fall of Tipu Sultan, more and more areas in South India came under the administration and governance of the East India Company. The Government of Fort St. George felt the need for an exclusive government press and established one in 1820. Meanwhile, 'natives' found enough capital and the need to establish a printing press. Saravanaperumalayar and Visakaperumalayar - two cousins - with adequate means ventured into book publication by establishing a publishing house named Educational Press at Kosepet (in Madras). Thiruvenkatachala Mudaliyar, a pundit in the college of Fort St. George, established Saraswati Press in 1834. Missionaries were also not far behind. SPCK established a press at Madras in 1815, and Religious Tract Society established a press at Palayamcotta in 1822. Printing presses were also established at Neyyur in 1821, at Jaffna in 1821, and at Pondicherry in 1840. By 1860s about 50 printing presses were operating in the Madras Presidency.

The new steam-powered printing presses brought the reading matter to ever larger audiences. The books available to buy or borrow were as varied as moral texts like Netineri Vilakkam to popular science books published by the Madras School Book Society or Christian Vernacular Education Society. The institution of literary clubs attached with reading rooms and libraries by the educated natives expanded the scope for accessing printed books.

Early popular science publications in Tamil

The Company administrators with a bent of scholarly attitude were keen to collect, preserve, collate, edit, and publish indigenous literary works. Tipu's library offered access to a collection of literature hitherto not easily accessible to the British. Indeed, the interest towards native literature was also inspired by the need for the administrators to be familiar with the life and ways of the population that they were governing. Thus, modest efforts were made to undertake the publication of books other than religious tracts and government reports and orders. The Company's effort at expanding the publication programme to include educational works of general nature received support from the then Governor of Madras presidency, Thomas Munroe. In 1820, he took the initiative to establish a series of modern schools to provide instruction to native children. Further, he established Madras School Book Society* in 1820 and provided a yearly grant of Rs 500/- to bring out publications in the native languages accessible to children and the general public.

One of the earliest known popular science works in print, 'Joyce's Scientific Dialogue' was an abridged Tamil rendition extracted from the seven-volume work by Rev. J James Joyce, published in Tamil around the 1820s. The publication was undertaken by the Madras School Book Society and drew upon the abridged version published by the Calcutta School Book Society. Nevertheless, a tract on cholera, composed in 1818 by Fr. Rhenius and a popular exposition of the contemporary ideas of Universe ‘Andapinda Viyakyanam' (discourse on cosmos), were noteworthy. They were written on palm leaves and as paper manuscripts, copied and circulated for wider reading.

Survey of popular science books (1820-1857)

During the early decades of the 19th century, prose appeared in the Indian vernaculars as a narrative form, side-by-side with the emergence of printed books. This provided a powerful tool for re-articulating perceptions of rapidly changing social order. As the project of modernity acquired new converts from segments of the population, schooled in the 'new knowledge,' new domains of reality became topics of prosody. Science became one of the themes in Tamil explored by authors at the turn of the 19th century. This period also marked the emergence of the Tamil Renaissance in-culture, literature and language.

	Before 1867	**1868-1880**	**1881-1890**	**1891-1900**	**1901-1910**
European missionary publications	25	15	6	9	4
Native institutions	6	7	4		4
Data not available	15	9	6	6	2
Brahmin		6	9	6	33
Native christian	3	3		1	2
Non brahmin		2	9	13	14
Total	**49**	**42**	**34**	**35**	**59**

Table 1: Tamil publications (books) on natural sciences$ (during the nineteenth century)

*MSB&VLS: Madras School Book and Vernacular Literature Society- authors are largely natives.

$Only books on natural sciences are counted. Books on mathematics, medicine, and health are excluded.

Source: Compiled from ‘Madras State Bibliography of books 1867-1900’ Tamil Development and Research Council, Volumes published in 1961, 62, 63 and 64; ‘Madras State Bibliography of books’ for the years 1911-15 and 1916-20 published respectively in the years 1974/77, and 1978; ‘Classified catalogue of the Public Reference Library 1867-89, 1890-1900, 1901-10, 1911-15, 1916-20, 1921-25 published respectively in the years 1894, 1961, 1964, 1964, 1965, 1971.

Table 1 provides a snapshot of popular science books authored between 1820 and 1910. It can be seen that while before 1867, the production of popular science was exclusively a missionary affair, by 1900, native authors contributed significantly. By the turn of the 19th century, the role of missionaries diminished while the native authors became dominant. Even within the natives, one can see the changes in the composition of social classes. It can be posited that with the change in the social classes, the nature and the content of the popular science varied (see Babu, 2000, Venkateswaran 2008). Thus, this paper examines the popular science books authored by missionaries in the early part of the 19th century.

After surveying various catalogues published in the middle and late 19th century, the information on the books published in Tamil on scientific topics was identified. The survey yielded 48 printed science books published in Tamil. The titles were confined to natural sciences (other than mathematics and medicine) published before 1857. We are aware that the methodology adopted to trace the books published in the early 19th century through secondary compilation may not be comprehensive and few works might have been inadvertently left out from various bibliographies and lists prepared earlier. However, the extract we have prepared (see Bibliographic listing) is highly indicative of the trends we seek to postulate.

One factor that is readily apparent from the above table is that during the first half of the 19th century, although native printing press was in existence, publication of popular science books in Tamil was largely a missionary affair. Even the books sponsored and published by the East India Company were authored by the missionaries. The market for popular science books was not as lucrative as say for literature, and hence the native printing and publication establishments kept a distance from publishing science books. The missionaries were able to seek philanthropic contribution for publication of various tracts and books from Europe and America and hence were bothered with the economics of book production and circulation. The East India Company supported initiative also thrived on the annual grant received from the government.

In addition to economics, perhaps the natives were diffident to venture into authoring and publishing a book on unfamiliar scientific topics. Native literati naturally saw themselves as adequately qualified in knowledge domains such as traditional remedies for illness or veterinary care, or scholarly works on Tamil literature. On the other hand, developments in natural science, especially in physics and chemistry (electricity, magnetism, electrochemistry and so on), would have overwhelmed the native literati. Lacking legitimacy the natives kept away from authoring and publishing works on science for the general audience, however, educated and well-informed missionaries prevailed in writing and publishing science. Even among educated Europeans, while English officials dabbled in various areas like history and archaeology, it was the missionaries who were considered as the educated experts in the areas related to natural philosophy and natural history. It is noteworthy that it was the clergy, the highly educated group amongst the Europeans in India, who were seen as legitimate purveyors of both secular and profane knowledge.

Education as missionary work

Evangelical belief in the transformation of human character through education and the conviction that conversion to Christianity required some amount of learning (Niranjana, 1992) prompted the missionaries to engage in the educational spear. As Lalitha Jayaraman (1986) notes *"... in the period before 1833, the missionaries mainly concentrated on establishing elementary school teaching through* *the medium of modern Indian languages…*" The missionaries had a close relationship with their spiritual mission of spreading the word of Gospel and were closely linked to the mundane colonial project of 'civilising the natives'. John Murdoch (1881) remarks*"…the aims of education are 1) to promote the temporal well-being of the people of India 2) to elevate them intellectually 3) to raise their moral character…"*. Nevertheless, the missionaries did not share the colonist's claim of intrinsic cultural superiority of the European 'race'. The missionaries advocated a far more non-racial viewpoint in their articulations (see Venkateswaran, 2013). If the natives were seen to be wanting in mental and moral capacities, for missionaries they were the result of 'false belief' (superstitions) and absence of 'true' education, rather than intrinsic lacuna of the 'native.'

Evangelist fervor fermenting in Britain, as well as partly influenced by the Scottish enlightenment movement, contributed to the blurring of the distinction between 'moral improvement,' civilization and Christianity. Thus, for the missionaries of that period 'mental, moral development of natives' was rhetoric for proselyting. Western cultural norms and modern scientific knowledge were seen to be aligned with the truths of Christianity and thus were seen as an ally in the 'crusade' against the 'superstitions of the natives.' Treating 'literature, philosophy, and science as aspects of the one morally informed source of authentic knowledge' was a strategy of missionaries 'to ground morality and social behaviour in an analytical appreciation of institution, obligation, and law' (Studedert Kennedy, 1998). At the same time, it was also an effort to establish a "connection made by reason, between Christian truths and empirical knowledge."

For example, the missionary Murdoch (1847) wrote to his family at Glasgow, *"...You ask about the telescope that you sent me. It answers the purpose tolerably. I may mention that it had a considerable effect on the minds of youth in causing him to disbelieve Buddhism, as it showed the mountains of the moon and the satellites of Jupiter. This may, perhaps, surprise you. I have however only room to mention that the religion of the people is quite opposed to European geography and astronomy, and, consequently, if the latter is true, the former is false..."*, in a naïve belief that some errors in native geography or cosmography could weaken Buddhism, Hinduism or Islam. In fact, the opposite occurred; western educated youth could use the very same modern science to question the dogmas of Christianity. It was argued that reading any science, or the history of the world, or the bible, must exercise upon their minds a powerful influence, and tend to dispel their puerile, pernicious and God-dishonouring notions, derived from their traditions on the creation of the world, of angels, of Muhammed, etc., and to instil in their hearts a sense of sin and justice, and of the fear and holiness of God. Their faith becomes sapped, and the Christian religion must command itself to their minds.' (Murdoch, 1870).

Discussion

Given that the authors were missionaries it is not surprising that moralizing and sermonising are readily apparent in the text. The preface and commentaries of the authors amply indicate that in the eyes of these pioneering science writers for children, the books given to children were meant to shape or prepare the young mind to the mental and moral improvement. For a young audience, it was crucial that the overtly technical language is avoided, concepts are explained lucidly, if necessary accompanied by a diagram or illustration, and blend education with entertainment as well as instruction with amusement. Adults might be willing to stay on with a book, in the name of the pursuit of knowledge; bored children would be more likely to simply close the book. Careful examination of these works reveals that an attempt was being made to blend moral instruction and rational entertainment engineered through the particular narratives deployed. One of the author, Rev. E Sargent (1874) reasons that the study of natural philosophy is *"not only for material progress but also for spiritual progress, one who acutely studies natural philosophy will realize the greatness, intellect, and kindness of the creator (God)."* That is by practice and knowledge of science; we can see evidence of his grace, mercy, magnificence, and power.

The missionaries adopted the narrative styles popular in Europe as well as explored the native styles to their advantage. More than one-fourth of the books published during this period, had a narrative of catechism or dialogue. While the catechism had a long Christian tradition, the dialogue was narrative often used by science writers from Galileo to Marcet to communicate counter-intuitive new reality domain to their readers. Catechisms, in its rudimentary form, could be just a series of questions and answers; but it could also be ornamented by way of casting two characters -- one to ask questions (say a student/ disciple) and the other to answer (teacher/ Guru). Most of the books under this category are in the questions and answers format between guru/disciple format. Although the intent of the catechist work was not to force the reader to commit to memory the answers or factoids, implicitly it suggested the reader to acquiescent to 'authority' and accepts the 'answers' as definite authoritative and absolute.

On the other hand, dialogues are a narrative form of arousal and delayed satisfaction of curiosity with a cast of characters, a plot pattern of interruptions, digressions, and topic shifts, leading to an ending. In the hands of the early science writers, tropes such as interruptions and digression were deployed not only to create a sense of suspense and thereby heighten the tension before it is resolved, but they also acted as a fictional device for kindling the curiosity and present competitive/ alternative perceptions. While on the one hand the 'fictional' narrative provided them with a latitude for making a ‘story' and thereby sought and held the attention of the reader. The form also allowed the creation of a virtual dialogue between the author and reader through proxy articulations of the characters and thereby appeal to reason.

Two distinct types of dialogue forms of narrative can be identified in the scientific literature - polemical dialogues and pedagogical dialogues. Polemical dialogues imagine an ideal scholarly discussion, while the pedagogical dialogues imagine an ‘ideal' classroom involving the all-knowing teacher and a trusting and receptive student/learner. Dialogue narrative is perceived to have an advantage for pedagogical purposes as it is said to mimic the process of a student's learning. It is striking to note that only two of the works sport 'dialogue' in their title, and both of them are pedagogical dialogues, perhaps indicative of the colonial mindset that viewed the natives, particularly native children as lacking in mental and moral capacities and hence had to be instructed in the same.

Native narrative formats, Upanyasams (discourse) and Pozhipurai (elaborations/ commentaries) were another dominant narrative styles adopted by the missionaries. These formats of narratives simultaneously elevated the social status of the European missionary authors in the eyes of the native literati, and at the same time enabled them to exalt their toil as a creative literary activity rather than as a mere ‘translations' from a source language to target language.

Early years of nineteenth century was not time ripe for a colonialist to dismiss ‘native’ knowledge with a single flourish, “medical doctrines which would disgrace an English farrier, astronomy which would move laughter in girls at an English boarding school (Macaulay T.B., 1835)” Superior military power may have been demonstrated by the Europeans, but the superiority in knowledge was yet to be fully demonstrated. Most of the Europeans the native encountered before the arrival of the missionaries were a vice, money-hungry traders and soldiers. Europeans were reproached and taunted as Feringhi, a country bumpkin, with little or no deep knowledge. When Rev. Swartz set off to visit villages around Tanquebar in 1758, he was astonished to be told by natives that *"We have books wherein the solar and lunar eclipses are accurately calculated, and according to those calculations the events happen"*, and based on the accuracy of these the natives interpolated that *"other points contained in these books, which concern the divine laws and heavenly things are in true also."* (Swartz, 1835). It became incumbent upon the European missionaries to establish their erudition and appear to be more knowledgeable than the native literati. 'Native pastors', a report of ABFCM (1856), argued that, 'should have a knowledge of the Sanskrit language, so that they may be prepared to answer the learned Brahmins and further stated that they should be acquainted with 'English science', so as to stand on an equality with those 'intelligent natives well acquainted with English science'.

Upanyasams were the traditional oral communication narrative format used by the native scholars for expositions on religious or philosophical works. Pandits and scholars well versed in the literature engaged in writing Pozhipurai (commentaries) on literary works. By deploying both these narratives, European missionaries sought to present their popular science writing as a creative literary description of the external world as well as giving the text the same exalted status the 'traditional Pozhipurai' commanded from the native society. It should be kept in mind, not just print, but even the verse was novel. Books of this genre had an extensive allusion to literary tradition, by way of illustrating points with quotations from Bible and other western scholars. Quotations often from western classical literature or at times from native secular literature by the authors embellished scientific texts and not only made it more readable and attractive but also elevated it to 'literary' work. Rendering science in the semblance of 'literature' also had another effect that the composition of the science books in Tamil. The act of producing such works was not to be seen are mere re-rendering or derivative activity but presented the authors as scholarly erudite 'Pundits' and thereby enhance their social status. Such quotes permitted the author to display their learning, liberal education, and familiarity with the 'native texts.' While the Bible, testaments and Christian fables provided the bulk of the quotes, native texts such as Tirukural were also often used. Literary native moral works like *tirukural*, canonized as devoid of 'idolatry' and 'superstitions' were appropriated for embellishing the texts. Quotes from the Bible enabled the European missionary authors to address their objective of 'mental and moral upliftment' of the natives and provided the necessary latitude for encoding moral and divine messages in the works. Further, the use of native narrative formats such as Upanyasams/ Kurippus / Pozhipurai assisted the authors in legitimising the work in the native literary and intellectual cosmos. As S.Irfan Habib (1989) and Dhruv Raina (2014) suggests, 'even an imported knowledge such as modem science, undergo acculturation to the extent that it begins to mirror the cosmos of the communities that take to it', the missionaries took recourse to 'native' narrative form to communicate their new ideas and the missionaries mirrored the 'native literati' in their format, style and narrative.

The life story of scientists, which is the staple of science writing during the late nineteenth and early twentieth century is strikingly absent in the early nineteenth century. Also, there are no picture books, albeit for technological reasons. In those days pictures or illustrations had to be etched and block made for printing. It was costly and laborious. Also absent is non-fiction writing, revealing perhaps the mindset that children would not be attracted towards them.

The landscaping forged by these pioneers became the established norm for the coming years. Many of the features such as "instructive and amusing," moral lessons, the use of the conversational style, embellishing the text with literary allusions and quotes and recourse to examples from everyday life became obligatory features in Tamil prose science writing for children in years to come.

Bibliographic listing of printed popular science books in Tamil before 1857

Books for Adults

1. Indico Cultivation, Agriculture, (Nd)
2. Maddu Vaagadam, (Diseases of Cattle), Agriculture (Nd)
3. Jothi Sasthram, (Oriental Astronomy), Hoisington H R, American Mission Press, Jaffna, (Nd)
4. Thattuva Sastram, (Natural Philosophy), Sargent E Rev, Palayamcotta Press, Palayamcotta
5. Bana Murai, (Gunpowder Manufacture)
6. Asuva Sasttiram, (Farriery)
7. Bhoomi Sasthram, Geography, Rhenius C Rev, Church Mission Press, Nagercoil, 1832
8. Goladeepikai, (Traditional Hindu astronomy), Saravanaperumaliyer, Kalarathnagaram Press, Madras, 1839

Dialogues & Catechisms

1. Joyce's Scientific Dialogues, Natural Science, (Trns. Cawmayappa Moodaleiyar), Madras School Book Society, Old College, Madras,
2. Dialogue On Physical Sciences, American Mission, Jaffna, 1843,
3. Natural And Revealed Law, Natural Science, Rev Dr. Spaulding, Jaffna Religious Tract Society, Jaffna, 1849, (Dialogue Between Father And A Son)
4. Jothisasthram, (Astronomy), Christian Vernacular Educational Society, Madras, (Nd)
5. Catechism Of The Elementary Geography, Jaffna American Mission, Jaffna, 1847,
6. Ilamail Kalvi, (The Little Philosopher) Rev WT Sattiananadan, 1857, (Conversation On The Heavenly Bodies &C For Native Children)
7. Siruval Kalvi Thunai, (Children's Guide To Natural Science- catechism of general knowledge)
8. Pumisastira Surukkam, (Short Notes On Geography), Nagercoil, 1846,
9. Thatuva Sasthra Vina Vidai, (Catechism Of Natural Philosophy), Sargent E Rev, Palayamcotta Press.
10. Tattuvanul Surukkam, (Brief Book On Natural Science- Astronomy, Natural History &c in question and answer), Nagercoil,

Primers

1. Browne's First Geography, Christian Vernacular Educational Society, Madras, (Nd)
2. Cliff's First Geography, Government Book Depot, Madras, (Nd)
3. Geography Of The Madras Presidency, Madras School Book Society, Madras
4. Manual Of Geography, Government Book Depot, Madras
5. Summary (Brief) of Facts On Physical Science In Tamil, (Soobaroyaloo B) Rev JW Thompson, Madras, Madras School Book Society, Madras, 1840, (Trans Of Rev JW Thompson's Work)
6. Geography For Small Children, Jaffna, 1840
7. Urthiri Vilangiyal, (Domestic Animals), Nagercoil, 1836,
8. Chamber Geographical Primer, Government Book Depot, Madras, (Nd)
9. Geographical Primer, Christian Vernacular Educational Society

Descriptive

1. Sketches Of Asia, Government Book Depot, Madras,
2. Sketches Of Europe, Government Book Depot, Madras,
3. Ganathin Pirivugal, (On Subdivisions Of Knowledge- Tr. from Dr Ballantyne's book), Madras School Book Society, Old College, Madras
4. Natural History Of Animals, Government Book Depot, Madras,

5. Vana Vilangiyal, (Animals Of The Wild), Nagercoil,
6. A Short History Of Mankind, Rev Rhenius, Madras Tract Book Society, Madras, 1827

Lectures

1. Pukola Sastirangkirakam, (Geography of The Madras Presidency), MKUS, Madras
2. Pumisasthrira Polippu, (Explaining Geography), Ceylon Mission, Jaffna,
3. Pumisastira Kkurippu, (Notes On Geography), Nagercoil,
4. Patharthaviyakyana Sasthra Vishayaman Upaniyasam, (Lectures On Natural Philosophy), Madras
5. Palavagai Thiruthananantham, (On General Knowledge, Natural Science), Rhenius C Rev, Madras Tract Society, Madras, 1827, (Treatise Refereeing To Miscellaneous Subjects Such As The Solar Systems, Some Of The Phenomena Of Nature, Astrology, The Hindu Chronology, Various Religion Of The World &C).
6. On Clouds, Rev W Taylor, Madras,
7. On Geography, Rev W Taylor, Madras,

Format not known

1. Vanasathra Surukkam, (Tr. from Outline of Astronomy - Hall), Edited by Spratt T Rev, Palayamcotta Press, Palayamcotta, (Nd)
2. Bower H Rev, Elements of Chemistry, (Tr from Ballantyne’s work) GDB, Madras, 1857 (?)
3. Scripture Geography, Christian Vernacular Educational Society, Madras
4. Astronomical Errors, Rev Dr Poor, Jaffna Religious Tract Society, Jaffna, M, 1832, M, A, (Shows The Errors Of The Puranic Systems Of Astronomy)
5. On Cholera, Rev Je Nimmo, Madras Tract Book Society, Madras, 1844, (2nd Edn 1847)
6. On Cholera, Jaffna Religious Tract Society, Jaffna, 1849,
7. Destruction of Superstition, Vedanayaga Sasthri, 1853

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ORCHESTRATING DIALOGIC DISCOURSE IN SECONDARY SCIENCE CLASSROOMS

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Classroom talk holds vast learning potential for meaning making processes in science classrooms. However, researchers observe that utilization of its learning potential in science classrooms has been somewhat neglected. This research investigated various purposes of teachers' discourse moves essential for orchestrating dialogic discourse in secondary science classroom settings using multiple case study research design. A fine-grained analysis of the purposes of the teachers' discourse moves was done using a coding scheme developed for the study. Implications are drawn for both science teachers and teacher-educators by identifying appropriate repertoire of strategies facilitating teachers to position themselves as 'enablers of talk for thinking' (Chin, 2006). 7

Introduction

Research in science education for long has been laying emphasis on the utilisation of classroom talk for meaning-making process (Mortimer & Scott, 2003; Michaels & O'Connor, 2013). Mortimer & Scott (2003) pointed out, "…the key feature of any science lesson (…) is the way in which the teacher orchestrates the *talk* of the lesson, in interacting with students, to develop the scientific story being taught." Specific forms of talk organization, such as, dialogic knowledge-building processes have been reported to augment students' engagement with the scientific concepts as well as practices (Kawalkar & Vijapurkar, 2013; Michaels & O'Connor, 2013). Despite studies accentuating the importance of dialogic interactions, talk in science classrooms is 'overwhelmingly monologic' (Alexander, 2001).

A prime reason behind the lack of development of classroom discourse for science meaning making is attributed to teachers' scant understanding of theoretical tools and strategies for using classroom discourse to its best effect (Michaels & O'Connor, 2013). This study examines teacher discursive moves and their purposes in whole class secondary science classrooms using multiple case study research design. A discursive move framework was developed using an inductive-deductive approach to make explicit specific purposes for which teachers' moves are directed to in dialogic science classrooms.

Dialogic discourse in science classrooms

It has been identified that the three-part exchange, Initiation-Response-Evaluation or IRE (Mehan, 1979) is the dominant discourse format in science classrooms. This three-part exchange structure can be monologic if the teacher evaluates students' correct responses with praise and ends it there, or it could be dialogic if the teacher chooses to use the third step to scaffold students' extension of knowledge (Chin, 2006). It can lead to open chains of the form −(I-R-P-R-P-R-) where P stands for teacher prompt or $I\text{-}Rs_1\text{-}Rs_2\text{-}Rs_3$-, where *Rsn* indicates a response from a particular student being addressed by another student instead of any evaluation being made by the teacher (Mortimer & Scott, 2003).

Mortimer & Scott (2003) developed a framework to characterize discourse patterns in science classrooms. They noted that non-interactive discourses do not provide any scope for bringing together of ideas and, are closed to multiple points of view. However, in interactive discourses, both the teacher and students contribute. The authoritative discourse is represented by the teacher' presenting the scientific canon of information, while the discourse supportive of dialogue encourages exploration and representation of diverse students' ideas.

Another strong influence on this research has been the concept of 'dialogic teaching' that emerged through the cross-cultural study conducted in many countries including India by Robin Alexander (2001). He noted that in the classrooms characterized by dialogic teaching, teaching is cumulative, reciprocal, purposeful, supportive and collective. Mercer & Littleton (2007) pointed to the use of 'exploratory talk' which lay emphasis on critical co-construction of knowledge. While extending the field of study further, Rojas-Drummond et al (2012) have created bridges between the theoretical traditions of scaffolding and dialogic approaches through the conceptualization of 'dialogic scaffolding'.

Teacher discourse moves

Krussel et al (2004) describe the teacher's discourse moves as having four essential components — *Purpose*: intended curricular and organizational aims; *Setting*: physical and temporal constraints; *Form*: can be verbal (comment, question, directive etc.) or non-verbal (gestures); *Consequences*: achieving intended purpose or movement in unanticipated directions. Teacher-discourse moves are instrumental in shaping the classroom atmosphere and setting the stage for student participation in classroom discourse (Roth, 1996).

However, one of the major obstacles to the organisation of dialogic discourse in classrooms is teachers' ignorance about the nature of moves they routinely employ in organizing the discourse patterns (Chin, 2006). This brings forth the need to make talk moves explicit, 'visible and object-like' (Michaels & O'Connor, 2013) so that teachers can reflect upon the use of specific talk moves and their relation to students' learning.

Purpose of the study

The following research question guided the study:

What purposes are served by teacher moves in a dialogic science classroom context?

Method

This study employs a multiple case study design (Holliday, 2007). It was part of a larger study that involved eight teachers from three different schools, who were teaching science to 14-15 year olds. Two teachers (referred to in this study as TA and TB) from one of the three schools, were purposively sampled for this study as a detailed analysis of their lesson observations conducted for a period of three months, when compared to others, indicated towards the presence of large amount of rich, interactive engagement of classroom community with diverse ideas in the scientific knowledge-building processes which can be viewed as important features of dialogic discourse (Mortimer & Scott, 2003). Teachers' profile is presented in Table 1.

Name of the teacher	Gender	Grade/s taught	Professional Experience	Educational Qualifications	Topic of the lessons observed
TA	Female	9 & 10	28 years in the same school + Headed the Science Department of the school at the time of the study	Bachelors in Science (B.Sc) + Bachelor in Education (B.Ed) + Pursuing Masters in Education (M.Ed) on part time basis at the time of the study	Force; Reproduction
TB	Female	9 & 10	14 years in two different schools and 3 years in this school	B.Sc + B.Ed	Gravitation; Light

Table 1: Teachers' profile

The average class size was 40 students per class. Teachers said owing to large class sizes, time constraints to cover a prescribed national science curriculum, and accountability pressures, they preferred guided discussion in whole-class contexts, and this became the particular focus of the study.

Discursive move framework

Using previous researchers, such as Hennessy et al (2016) and Tytler & Aranda (2015), a coding scheme for examining purposes of teachers' discursive moves and their purposes was evolved for the study. However, later it was realised that the categories were not truly characterising the ideas emerging. Hence, using an inductive approach, a discursive move framework was evolved which is listed in Table 2.

The emerging codes and their description (as reported in the paper) are shared with another researcher who independently coded the moves as observed in transcripts of classroom observations. There was around 90% agreement in coding by the two researchers. The differences were resolved upon revisiting the data followed by discussions.

Data sources

Non-participant observation was used for data collection, as this ensured that everything documented includes and reflects the researcher's interpretive framework (Holliday, 2007). My presence as a researcher in these classrooms was non-invasive, as I did not have any control over the issues of choice of topic, when and how to teach, and the like.

Data sources include audio files and videotapes of science lessons, copies of any teaching–learning material given to students, and notes of semi-structured interviews carried out with teachers (a total of six hours of interview of both teachers). All audio files were transcribed verbatim. Twenty lessons (10 from each teacher), comprising about thirteen hours, constitute the data analyzed. The lessons covered topics such as sources of energy, reproduction, chemical bonding, light, etc.

Data analysis

Each teacher utterance was coded using Table 2. Sometimes, a move served more than one purpose and all of them were noted. This is in line with Roth's (1996) observation that polythetic classification schemes (which allow an observation to be assigned to multiple categories) are appropriate in handling the complexity of human discourse. Coded data was analysed using quasi-statistical style which employed use of frequency counts.

Following this, a sequence of talk stripped of code was shared with science educator, who independently coded teacher moves using the discursive framework in Table 2. The coding was most consistent for codes such as 'Making specific invitations' (the teacher soliciting response from any particular student) but became less consistent for more conceptual codes that required a high level of inference. Discussions following this process of revisiting the data clarified the judgments made by the author.

Purposes of teachers' discourse moves	**Codes**	**TA**	**TB**	**Total**	**Proportion of teachers' moves**
1. "Setting the stage": Baseline assessment				113	0.202
Drawing out experiences	DEx	3	12	15	0.027
Ascertaining understanding of pre-requisites	AscP	6	7	13	0.023
Focusing on previous work	FoP	14	13	27	0.048
Soliciting factual knowledge	SolFK	12	14	26	0.046
Provoking Ideas	PI	13	19	32	0.057
2. Examining processes of learning				75	0.134
Extension of the concept	Ext	17	5	22	0.039
Justifications	Just	13	6	19	0.034
Predictions	Prec	4	3	7	0.013

Elaboration	Elb	12	7	19	0.034
Ways to find out	T	1	4	5	0.009
Inferences	I	3	0	3	0.005
3. Encouraging wider participation				97	0.173
Asking authentic questions	AQ	19	4	23	0.041
Making specific invitations	SpIn	11	23	34	0.061
Authoring students' accounts	AuhA	21	8	29	0.052
Positioning accounts with respect to one another	PoA	8	3	11	0.02
4. Talk structuring				167	0.298
Repackaging	RP	12	5	17	0.03
Revoicing students' questions/statements/ comments	ReV	10	7	17	0.03
Passing on scientific canonical knowledge	ScK	23	27	50	0.089
Building upon previous argument	Sar	27	32	59	0.105
Delineating learning objectives	CLO	13	11	24	0.043
5. Developing problem solving strategies				108	0.193
Asking for viewpoints	AskV	16	13	29	0.052
Tackling agreements/ disagreements	AgD	11	5	16	0.029
Consensus building	Bcons	15	11	26	0.046
Asking for application of knowledge	Apl	3	1	4	0.007
Prompting	Prom	13	20	33	0.059

Table 2: Number and proportion of teachers' dialogic moves from each category for both the teachers

Results & Discussion

Purposes of teachers discourse moves

My analysis of the purposes for which teacher's discourse moves as employed in a dialogic classroom discourse led to the identification of five broad categories, given below. The sub-categories within the five broad categories and the proportion in which they were used in each teacher's class are given in Table 2.

Conducting baseline assessment

Teachers often began their class either by gauging students' understanding of pre-requisites; for example, before beginning to develop an understanding of forms of cellular division, the teacher quizzed students on their understanding of cytokinesis and karyokinesis; or, by drawing out what had been taught in previous classes by asking questions such as, 'Do you remember the slides we observed in the last laboratory session?' These moves often helped students to relate to what they already knew, and connect to past shared experiences to carry ideas forward for future activities.

Engaging in scientific processes

Teacher TA remarked, 'Science is not only about product; it is the process of arriving at scientific knowledge'. Both the teachers' moves constantly encouraged students to make explicit their thought processes by using a variety of ways, such as, asking for elaboration ('Oh! interesting, would you like to shed more light on that?'), explanations, justifications and reasons for arguments. Teachers developed scientific processes among students by providing them hints through which they could themselves build the scientific story. For example, TA enabled students to connect image formation in a convex lens when an object is placed at infinity with an activity conducted in a previous class where they had attempted to burn a piece of paper by focusing sunlight through a magnifying glass on it.

Encouraging wider participation

Teachers not only encouraged diverse responses but worked towards engaging all students in the pursuit of meaning making by explicitly inviting passive students, authoring accounts so that students begin to hold responsibility for their accounts, and then positioning students' accounts in relation to one another to develop coherence in the dialogue. By using authentic questions, such as, 'Would anybody like to add to X's comment?', and so on, the teachers invited opinions that pulled less-vocal students into the classroom discourse.

A classroom excerpt from Teacher TA's class where she was teaching the concept of "fermentation" is presented underneath. Each teacher move is coded using codes from the discursive framework developed for the study (see Table 2):

T: Have you eaten stuff like bread, dhokla... (DEx)

Many students raised hands, spoke about their breakfasts etc.

T: Do you know we require a micro-organism for bread to make it eatable? (AscP, PI)

Students were wondering

T: Have you observed that dough for dosa is kept in sunshine before it is used for cooking? (PI, DEx)

Student shared their experiences

S2: Ma'am, it gets fluffy…

T: S2, what is it that makes the dough fluffy? (Elb, SpIn, ReV)

S2: I mean… I am not sure…

T: Ok, Can anybody suggest what makes milk get converted into curd? Does anybody know? (PI, AQ)

One student raised hand…

T: S5, please explain… (SpIn, Elb)

S5: We put one spoon of curd in lukewarm milk and it ferments in few hours.

T: Wait, what happens to the milk... (Ext, CLO, Prom, ReV)

Teacher focussed students' attention on the scientific vocabulary.

S5: It ferments…

T: What as per you makes the milk ferment? ...(Pause)… S2, can you relate with S5's observation (PoA, Just)

S2: I think…is it same in both the cases… may be…

T: S2 and S5 are pointing that in food items like dosa, curd a process, namely, fermentation occurs…. What do others have to say about it? (Ref, AQ, ReSQ)

S6: I have heard the term before…it might be alright…but the thing is …what is happening in fermentation?

T: Good question, so firstly do we agree that fermentation is a scientific phenomenon used in production of food items like dosa, bread, dhokla, curd etc… (BCons)

T: Do all of you agree? (BCons)

There seemed to a general agreement with most of the students nodding.

T: So, let's move on to what happens in it? (CLO)

T: What do you think happens in the process of fermentation? (Just, AskV)

S7: Not sure…

T: others please suggest… It is here where the micro-organism enters in (Cue, AskOp)

Students wondered which micro-organisms.

T: Do you remember the slides of micro-organisms that reproduce by the process of budding? (FoP, PI)

S6: Yeah… yeast is the micro-organism that reproduces by the process of budding

T: ... and, it is responsible for the process of fermentation… (ScK, Sar, ReV)

T: which division takes place first… cytoplasm or nucleus? (SolFK)

S1: cytoplasm

S2: nucleus

S3: karyokinesis

T: ok S3, tell me what do you mean by it... (SArg, Elb, ExIn)

(teachers' attention got trapped by the introduction of scientific term which she herself intended to introduce)

S3: Ma'am, I've heard it somewhere. Don't know…

S4: Ok, Ma'am, tell me is it related to something like… cytoplasm or nucleus division.

T: yes S4, you are almost there, it is the process of nuclear division and drew diagrams simultaneously (ScK, Sar, AuhA)

T: and cytokinesis would be… what do you think? (Ext, AQ)

Ss: division of cytoplasm

Talk structuring

Teachers were found to be providing enough flexibility to students to express diverse opinions, however, they sometimes constrained 'degrees of freedom' (Mercer & Littleton, 2007) by providing scientific canonical information themselves to steer the direction of the discourse towards the school science view. Teachers

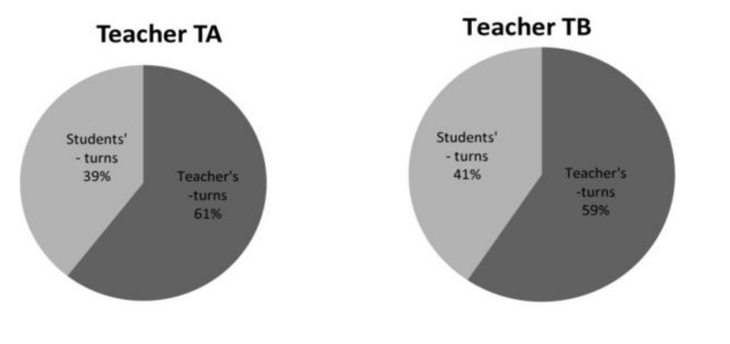

Figure 1: Frequency of teacher and student turn in each teacher's classroom discourse

used plenary sessions to reformulate curricular objectives achieved through the lesson, rephrased students' comments, questions, observations and, sometimes, took longer turns to explain the scientific content being missed by the students. Lesson observations point towards large number of turn taking by students which were used by teachers as launching pads for building further scientific concepts (see Figure 1).

Developing problem-solving strategies

Teachers' moves in pursuing dialogic discourse were not restricted to subject content only; rather, they used these opportunities for demonstrating problem-solving strategies to students. Teachers' moves provided students with mental models like that of seeking points of view, comparing them on the basis of reasoning, providing and accepting criticism constructively and working towards joint intellectual endeavours.

Conclusion

This study attempted to make teacher moves 'visible and explicit' enabling their easy implementation in classrooms. Talk awareness generated through this study would foster researchers, practicing teachers and teacher educators to make deliberate and constructive shifts in their discursive practices in science classrooms.

It is recognised over here that moves are not value free rather they are developed for achievement of specific purposes. Different teachers may deploy these moves variably depending upon their respective personality structures, teaching styles, and other context-related factors, as illustrated through the distinct patterns in which dialogic interactions organized by the two teachers in the study. Teacher TA embodied a much higher regard for examining students' processes of learning, perhaps, to scaffold the development of scientific concepts and processes through discourse while playing down setting of stage moves. On the other hand, teacher TB laid less stress on examining the processes and deployed more of setting-the-stage moves (see Table 2).

By running frequency counts on the purposes of teachers' moves as used by two teachers in the study, it emerged that teachers used highest frequency of talk-structuring moves (see Table 2), suggesting that students do not participate in science-classroom discourse themselves; rather, teachers in the study provided specific opportunities for their engagement.

Directions for future research

Further work in the direction of establishment of 'discourse-cognition relationship' (Westgate & Hughes, 1997) is required to ascertain the relationship between communicative and cognitive functions performed by the classroom discourse in science classrooms.

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ADDITIVE MODEL OF LANGUAGE POLICY AND HYBRIDITY: GLIMPSES FROM NUMERACY LEARNING IN EARLY GRADES IN A SOUTH AFRICAN PROVINCE

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One of the major challenges during mathematics lessons is the inability to use diversity of languages as a resource right from the early Grades. This complexity leads to a misalignment between language policies and educators' practices. This paper explores early Graders' numeracy language acquisition during development of their numerical skills and unpacks the dilemma in using Language-in-Education Policy. Data is drawn from interviews with pre Grade R learners' and classroom observations which are thematically analysed. Results show an emerging hybrid nature of early Graders' numeracy language and problematise the recommended additive model.

The tension

Current research highlights that one of the main factors influencing the struggle to improve learners' performance in mathematics is the role of language in supporting and nurturing meaningful learning of mathematics. Research on the role of languages has influenced policy makers such that language policies adopted in many countries have been structured to ensure that learners receive instructions and learn in their home language, particularly during the foundation phases, which in case of South Africa is Grades R to 3 (DoBE, 1997; RNCS, 2002, DoBE, 2011). The pedagogical basis of the Language in Education Policy (LiEP) is an additive model of multilingualism which calls for building learners' repertoire of linguistic resources, not only by maintaining and developing the home language and using it for LoLT, but also to learn other (African) languages (Bose & Phakeng, 2017). This model considers language as a resource as the ideal orientation of language for multilingual mathematics classrooms over the two other orientations, namely, language as a right and as a problem (Planas & Phakeng, 2014). However, not surprisingly though, it is the economic and political power of English that continues to dominate the classroom pedagogy in many developing countries, while learners in the classrooms continue to use their home languages for accessing and making sense of mathematical concepts (Adler, 2001; Feza-Piyose, 2012; Setati, 2005; Webb & Webb, 2008). Such classroom practices often lead to enhanced hybrid or in some cases distorted form of home language, which ultimately lead to an anglicised version often accepted as the home language. The tension therefore is whether or not such practices protect the additive model and preserve the spirit of multilingualism.

This paper unpacks the above tension of non-alignment of LiEP drawing from a case of pre-Grade R learners' numeracy language acquisition, as viewed from a larger ongoing NRF-funded indigenous knowledge system (IKS) education project. This paper also explores the effect of LiEP on South African Grade R learners' mother tongue acquisition. In particular, we address the following research questions:

1. What is the nature of pre-Grade R learners' numeracy knowledge in the light of LiEP?
2. Does LiEP facilitate mathematical proficiency among the learners?

South African indigenous languages

An interesting statistic suggests that around 30.3% of world's existing languages originated in Africa, yet only 11.8% of world's population uses one of these languages as their first language (Nkuna, 2010). By contrast, around 3.5 % of the existing languages originated in Europe, while 26.3% of the world's population uses one of these languages as their first language. This suggests that, although Africa produced almost ten times as many languages as Europe, fewer speakers use languages that originated in Africa as their first language, compared to those that originated in Europe and Asia. Ten of the 11 official languages of South Africa originated in Africa, which is only 0.5% of the 30.3% of all existing languages that originated on this continent. The question that now arises is: To what extent have these 10 languages strengthened South Africa's efforts to create an equitable society and emerge as a strong leader in the global scenario? And, to what extent has LiEP succeeded in transforming the previous language policy that promoted bilingualism, to the contemporary policy that aims at promoting and nurturing 11 official languages and also the indigenous languages?

Language as a resource

It is now widely recognised that there is a critical relationship between the learning of mathematical structures, and the language in which these concepts are learnt (Phakeng, 2016). Studies undertaken in the first half of the previous century generally considered bilingualism (the discussion on multilingualism appeared much later in 1980s) as having a negative impact on learners, a negative impact on language development and on educational attainment, giving rise to language confusion, a reduction in thinking ability, a decrease in intelligence, etc (Reynold, 1928 as in Grosjean, 1982; Saer, 1923, as in Phakeng, 2016). These studies were mostly reported in psychology books and journals. This negative notion with regard to bilingualism began to turn around after 1962, following a study by Pearl and Lambert. It was only much later that multilingualism and language diversity came to be seen as a resource, beginning with the work of Jill Adler in the 1980s. These studies helped in providing an informed direction for the formulation of language policies. While most language policies are guided by the notion of nationalism, some view the presence of more than one language in classrooms, and language diversity in the community, as a potential resource. However, it is one thing to preserve and promote local and indigenous languages, but it is quite another to promote and celebrate language diversity. The literature on multilingualism provides some direction towards achieving this goal.

Influence of colonial language on contemporary language practice

Continued use of the colonial language which has emerged on the international scene as the language of power, results in a greater demand for it by the South African parents. This trend relegates other South African languages to the social domain and creates huge obstacles for them to even stay alive. Globalisation, social mobility and modern ways of interaction based on technological advancements, have increasingly created mixed, or hybrid languages that many children learn at an early age. Such hybrid languages do not conform to any particular semantic or linguistic structure. Barwell (2016) argues that, in the contemporary society, teachers often face situations where learners draw from different languages and language practices, and use a hybrid language. However, it is also evident that some learners are not completely familiar with these languages. Barwell calls such situations "contexts of super diversity" (2016, p. 36) in that teachers themselves face challenges with the prevalence of these hybrid languages. We believe that the emerging phenomenon of super diversity creates a *dilemma* for teachers, in terms of following, on one hand, the existing language policy and promoting its objectives, and on the other, to ensure effective pedagogic practices. An analogous situation which emerged from classrooms in Pakistan is described by Halai and Muzaffar (2016, p. 67). They highlight the inability of an overly restrictive language policy to recognise and draw on the "cultural and linguistic diversity of the learners". Using Nancy Fraser's framework for evaluating policy implementation, and following the three dimensions of redistribution, recognition and participation in mathematics classrooms, Halai & Muzaffar demonstrate the paradoxes inherent in the implementation of language policies. They argue that it is the recognition of cultural capital (including language capital) and the inclusive use of languages that is needed, rather than an "abrupt move from one language to the other" (2016, p. 58). Although Halai & Muzaffar argued against the policy-driven positioning of English – which did not recognise the marginalised position of teachers, learners and non-English speakers, and hindered the redistribution of knowledge of mathematics and English – our take on the South African context is somewhat different. It is the question of promoting and preserving the indigenous South African languages that is at stake rather than greater access to English – as in the case of Pakistan. Thus two different kinds of tension are at play in terms of the multilingual contexts of Pakistan and South Africa respectively.

Research has also underlined the socio-cultural role that language plays in the teaching and learning processes in classrooms (see Bose & Clarkson, 2016). For example, multilingual classroom contexts often show a fluid interaction between learners' home language, work-context knowledge (language in the neighbourhood), LoLT, and the dominant international language. Learners' explanations and discussions of this phenomenon reflect the socio-cultural nuance that their "language of comfort" carries. Learners' use of language is often aligned with the socio-cultural cues that the community holds. Although similar to the contexts of India and Pakistan, as seen from the South African perspective, it is not just about the non-recognition of indigenous languages, but about the non-alignment of classroom language practice with the existing language policy.

Research on language diversity highlights the continuous tensions created by discordant language relationships in learning mathematics (e.g. Barwell, 2009). Barwell argues that language relationships exist "between language and mathematics", "between formal and informal mathematical language", and "between students' home languages and the official language of schooling" (2009). This challenges the way forward in terms of policy formulation for LoLT. Research on the effective use of more than one language in the classroom suggests an increased use of code-switching as a means to achieve a more inclusive language usage by the learners in the mathematics classroom (Bose & Choudhury, 2010; Halai, 2009; Setati, 1998; Webb & Webb, 2008) and also recorded the potential power of 'exploratory languages' in promoting multilingualism.

However, more in-depth discussions is required on classroom situations where the dominant language, that is, English, tends to prevail over the home language of learners in the process of code-switching. In this context, this paper focuses on the overarching relationship between the official language of schooling (which may be same as LoLT), and students' home language, which, under certain circumstances, creates a dilemma for teachers. It further highlights the paradoxical effects of LiEP as indicated by an ongoing study.

Methodology

In an attempt to gain insight into the learners' ability to deal with numerical concepts within the context of the classroom, this paper employs a qualitative approach to examine the issues mentioned earlier. The unstructured interviews used, served to accommodate learners' interests and removed classroom pressures to allow learners to behave naturally. Additionally, the classroom videos employed, provided educators with an opportunity to enhance their teaching methods.

Research design

Participants

Twenty-six Grade R candidates were randomly selected from 13 classrooms in the Eastern Cape Province to participate in interviews prior to formal instruction. The study involved six primary schools, 16 Grade R teachers, and two Grade R learners from 13 classrooms. Each of the 16 educators involved in the project, submitted 5 video-taped lessons. The educators used colleagues from the same school to assist them with video-taping so as to avoid having strangers in their classrooms. Due to the poor quality of some of these video recordings, only 3 lessons per educator could be used, thus adding up to 48 lessons. In this paper only two educators' lessons are reported on as they represent the majority of classroom practices.

Instruments

Instruments for the study involved administering unstructured interviews designed to allow learners to first use their play time with the manipulative. This allowed the learners to get used to these manipulative. Interview time was negotiated with the learners after they had spent some time with the manipulative and had become familiar with them.

The researcher used a classroom observation tool to observe the lessons from the videos which included several repetitive questions worded differently to assist with the triangulation. This instrument helped the researcher to capture in detail, various classroom activities that otherwise could have been easily ignored. The instrument is called COEMET (Classroom Observation for Early Mathematics Education Teaching), and was designed by Clements and Sarama (2008). It was adapted in 2015 by Feza to suite the South African context.

Data collection

Data for the study was collected by conducting interviews with the sampled new Grade R learners, and on observation of lessons conducted by the selected teachers. Interviews with Grade R learners were conducted in all six schools by a group of researchers, over two days. Each interview lasted about 20 minutes. These interviews were audio-recorded to keep track of the verbal communications, and were also video-recorded to document the actions and gestures of learners. The video lessons were provided by the 16 teachers based on selected lessons, and were shared with the researchers.

Data analysis

The audio recordings of the interviews were transcribed into an MS-Word document and analysed using an iterative process designed by Miles and Huberman (1984) for developing codes and for contrasting instances. The codes were then triangulated with the literature used in this paper to reveal particular themes. The codes and the themes were discussed by two researchers involved in the study, and any differences were reconciled.

The classroom data that was captured using the COEMET tool helped to identify the most salient themes and assisted in analysing teachers' practices in the 48 lessons. Two researchers captured the data from the COEMET-instrument into an Excel sheet independently. Emerging patterns were documented as codes. The codes were compiled and discussed, and new analytical memorandums were written and integrated with the codes. The primary themes which emerged from the data will be discussed in more detail below.

Language practice: glimpses from lesson transcripts

Hybrid home language used by Grade R learners

Interviews with the learners indicated that the use of their home language (i.e. Xhosa) drew on several words from English. This characteristic was visible in most learners and particularly in their use of words for numbers (names). Learners counted in English and not in Xhosa although their LoLT was Xhosa. Interestingly, learners referred to the English number words as Xhosa words. This fact showed that these learners' home language has become mixed with English words, resulting in a hybrid language (i.e. a mix of the home language and the dominant language) – a growing practice which goes against the spirit of preserving and promoting home (African) languages.

Episode 1

Learner A

Interviewer: *Mingaphi iminyaka yakho* (How old are you?).

Learner A: Miyi six (I am six).

Interviewer: *Khandibonise usix* (Show me [the number] six).

Learner A: Shows a thumb.

Interviewer: *Khambale* (Please count it).

Learner A: One, two, three, four, five, six, seven, eight, nine ten (counting all fingers).

Learner B

Interviewer: *Mingaphi iminyaka yakho?* (How old are you?).

Learner B: Five.

Interviewer: *Khandibonise u five.* (Show me five).

Learner B: Shows her hand with five fingers.

Interviewer: *Khandibalele* (Count them for me).

Learner B: One, two, three, four, five (touching each finger with her lips as she counts).

Learner C

Interviewer: *Mingaphi iminyaka yakho*? (How old are you?).

Learner C: Shows five fingers.

Interviewer: *Lithini elinani undibonisa lona* (What number are you showing me?).

Learner C: Five.

Interviewer: *Ndibalele* (Count that for me).

Learner C: One, two, three, four, five (counting each finger).

Learner D

Interviewer: *Mingaphi iminyaka yakho*?

Learner D: Shows the thumb.

Interviewer: *Ngubani lo* (imitating the demonstration of the thumb).

Learner D: Six.

Interviewer: *Khandibalele* (Count for me).

Learner D: One, two, three, four, five, six (starting from the little finger to the thumb of the next hand).

Non-alignment with policy, curriculum and perceived home language

The excerpts below in Episode 2, show that all four learners were referring to English number words as being Xhosa words. Learner B mentioned that she preferred to count in Xhosa [Ngesi Xhosa], which is her home language, but when she counted it was pure English. While LiEP promotes multilingualism, it also emphasises that in early grades (i.e. up to Grade 3), LoLT must be in the learners' home language. We argue here that, while code-switching is useful in mathematics classrooms, what emerges from Episode 2 is not code-switching but a misrepresentation of language. Such a misrepresentation amounts to a non-alignment with the adopted language policy and fails to uphold the underlying objectives of nurturing and promoting indigenous home/African languages.

Interestingly, the learners interviewed in this study were all fluent in their home language which was Xhosa, but during the mathematics lesson they referred to mathematical registers in English, and these English registers were then perceived as terminologies in home language. This became evident from Learner B's response in Episode 2 below. Learners perceived their home language in a form that is, in fact, foreign to their actual home language. In this instance, the learners perceived English words as being Xhosa words.

Episode 2

Learner A

Interviewer: *Khandibalele ngesi Xhosa* (Please count in Xhosa).

Learner A counting to 12: One, two, three, four, five, six, seven, eight, nine, ten, eleven, twelve, ziyi twelve (they are twelve).

Learner B

Interviewer: *Yeyiphi indlela othanda ngayo ukubala sisiXhosa okanye iSingesi*. (How do you prefer to count, in Xhosa or in English?)

Learner B: Ngesi Xhosa.

Interviewer: *Khandibalele iminwe yakho ngesi Xhosa* (Please count your fingers in Xhosa).

Learner B: One, two, three, four, five, six, seven, eight, nine, ten (touching each finger with her lip).

Learner C

Interviewer: *Khandibalele iminwe yakho ngesi Xhosa* (Please count your fingers in Xhosa).

Learner C: One, two, three, four, five, six, seven, eight, nine, ten (counting each finger).

Learner D

Interviewer: *Uyakwazi ukubala ngesi Xhosa?* (Can you count in Xhosa?).

Learner D nods and counts: One, two, three, four, five, six, seven, eight.

Implications and looking ahead

Following the apartheid era when South Africa enacted its language policy by according official status to its 11 languages, including the two dominant languages English and Afrikaans, the policy was seen as progressive. This policy promoted a sense of nationalism with the aim of addressing the economic exigencies by defining a new ideological orientation. Although this policy gave indigenous languages, the socio-cultural, academic and global attention they deserved, the disparity between English and the indigenous African languages remained in force. Analysis from our data shows that the language policy (LiEP) has remained dogmatic and rigid while the promotion of indigenous African languages as envisaged in the policy remains limited.

Affective factors: the invisible learners

Our classroom observations and interviews with the learners showed that, although regular classroom practice appears to focus on the implementation of LiEP, the essence of the policy, namely to promote multilingualism, continues to fail. The learners' language resources drawn from the environment and from their community and experiences remain unacknowledged in the classroom. In the current study, the primary focus in terms of language management is confined to the home language, namely Xhosa, at the expense of other potential linguistic resources. We argue that the learners become invisible in the garb of policy implementation. This is a possible reason for the learner's numeracy development in the dominant language (i.e. English), due to the social environment, which is reinforced both at school and at home. The enactment of the policy therefore remains at the implementation level in the classroom, without connecting with the learners' social environment during classroom practice. Learner continues to remain invisible throughout the entire policy implementation process.

Hybrid languages and skewed numeracy cognition

Utterances in both Episodes indicate the dominance of English which has penetrated into the less 'powerful' languages, for example, the pre-Grade R learners found it convenient and natural to recite count numbers in English while thinking that they were speaking in Xhosa. Such penetration of English into other indigenous African languages has promoted hybridised languages which have led to learners' perception of a home language which is in fact foreign. It is also interesting to observe that a few learners who could count in Xhosa had done so by establishing a one-to-one correspondence between number words in English and those in Xhosa. The number cognition of the learners revealed that they mapped number-words with words already known in English indicating skewness in the learners' number cognition.

Semantic differences between languages

Numeracy knowledge in English is difficult to transfer to Xhosa. Xhosa number-words reflect place values when written in numerals. For example, eleven in English translates in Xhosa to *ishumi elinanye,* which is “ten and one”. Similarly, *ishumi elinesibini,* which is “ten and two”, stands for twelve; *ishumi elinesithathu,* which is “ten and three”, stands for thirteen, and so on. Twenty in Xhosa is *amashumi amabini,* which is “two tens”; twenty-one is *amashumi amabini ananye,* which is “two tens and one”; twenty-two is *amashumi amabini anesibini,* which is “two tens and two”; twenty-three is *amashumi amabini anesithathu,* which is “two tens and three”, and so forth. These semantic differences, however, make Xhosa number-words more comprehensible, because the English number-words are comparatively shorter and therefore easier to express. Learners' exposure to the omnipresent hybrid language due to the influence of technology-enabled gadgets and tools, makes it easier for them to pick up English. However, forced detraction from English and the abrupt adoption of the home language could also be detrimental. Rather balanced development of both languages needs to be promoted.

Language policy in South Africa is evidently no longer in consonance with the changing nature of language diversity witnessed in the mathematics classrooms. The outcomes are no longer aligned with the aims of policy. If instruction received by Grade R learners is not aligned with their numeracy language levels and conceptual development, it has little to contribute towards learning. LiEP in the current form is not speaking to the society and to learners’ homes but it only speaks to schools and in this process, it is creating a deficit among the learners. The exclusive nature presented by the LIEP entrenches more power to English. The multilingual nature of LiEP is explicitly helping in promoting the purist view of language which works against the pluralistic character of the South African society and the global world. LiEP should become a society language policy instead of a school language policy.

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ARE WE READY FOR TECHNOLOGY IN THE CLASSROOM?: UNIVERSITY TEACHERS' PERSPECTIVES

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With technology invading and enhancing all aspects of our lives, its impact on educational setup requires closer scrutiny. Many countries around the world have been successful in implementing paperless, blackboard-less teaching-learning activities in the classroom, along with research focussing on development of user-friendly apps for learning. The Indian government in its 11th and 12th five-year plan, lays emphasis on bringing technology to classroom by providing adequate funds for developing infrastructure and creating digitized resources and databases. In order to convert this vision into reality, the teachers are required to shoulder responsibilities. It, therefore, becomes imperative to ascertain and analyse their views about the role of modern-day technology within their classrooms. The present study has been conducted with university teachers to explore their perceptions about the change which technology could possibly bring in their pedagogy. Do teachers find their pedagogies sufficient and effective for students' learning? Are they willing for a change and wish to deploy modern-day technology in their teaching? What role do they foresee technology playing in their teaching and learning? What impact do they envision on learning environment and outcomes?

Introduction

One of the most outstanding achievements of our generation has been the development and dissemination of technology and its use across social spheres and strata. ICT (Information and Communications Technology - or technologies) is an umbrella term that includes any communication device or application, encompassing: radio, television, cellular phones, computer and network hardware and software, satellite systems and so on, as well as the various services and applications associated with them, such as video conferencing and distance learning (Lubbe & Singh, 2009). ICT in education particularly corresponds to use of technological tools to facilitate the teaching and learning process. The use of ICT in education does not merely reflect the use of technology to assist teaching; it has rather changed the meaning, methods and implications of education. Use of ICT is now frequent, marked by innovative trends. Many recent studies have attempted to grasp and analyse the changing scenario. Though extensive work has been done in this regard across the globe, I will mention a few studies focussing on tertiary level. These studies have made attempts to analyse the impact of ICT at various stages. Interestingly, the complexity of ICT and its relation with varied aspects have been highlighted.

Feasible association of technology with younger generations is often assumed, but does it have a corresponding effect on learning as well? Lai & Hong (2014) undertook a study highlighting that digital technologies form an inextricable part of young people's everyday lives. They conducted a survey with 799 undergraduate and 81 postgraduate students at a large research-intensive university in New Zealand to document their use of digital technologies on university as well as social activities and compared three age groups of students (under 20, 20–30 and over 30 years). The findings showed that while students spent a large amount of time on digital technologies, the range of digital technologies they used was limited. Also, their study identified that there were no practical generational differences in the technology use pattern and learning characteristics.

Digital technologies are now integral aspects of the students' experience. Henderson, Selwyn, & Aston (2015) aimed to investigate this aspect in their study, exploring students' actual experiences of digital technology during their academic studies – highlighting the aspects of digital technology use that students themselves see as particularly helpful and useful. Drawing on a survey of 1658 undergraduate students, their work identifies 11 distinct digital 'benefits' – ranging from flexibilities of time and place, ease of organizing and managing study tasks through to the ability to replay and revisit teaching materials, and learning in more visual forms. While their data confirm digital technologies as central to the ways in which students experience their studies, they also suggest that digital technologies are not 'transforming' the nature of university teaching and learning. As such, university educators perhaps need to temper enthusiasms for what might be achieved through technology-enabled learning and develop better understandings of the realities of students' encounters with digital technology.

Another study catered to an extremely popular and used arena of the digital technology i.e. social networking. Hamid, Waycott, Kurnia & Chang (2015) mentioned that the recent popularity of social technologies has motivated some university lecturers to use them for online social networking (OSN) educational activities. However, there have been limited studies assessing how to use social technologies effectively and what are the impacts on students' learning experiences, particularly with regard to their value in enhancing interactions. A thematic analysis revealed that students identified a number of positive outcomes from using OSN to interact with each other and with their lecturers. The findings contributed to understanding about how students leverage social technologies to enhance interaction among themselves, with their lecturers, and with the content of the course.

One of the very significant changes in terms of classroom organisation has been the move towards 'flipped classrooms'. A flipped classroom is a pedagogical model in which the typical lecture and homework elements of a course are reversed. Short video lectures are viewed by students at home before the class session, while in-class time is devoted to exercises, projects, or discussions. During class sessions, instructors function as coaches or advisors, encouraging students in individual inquiry and collaborative effort. Abeysekera & Dawson (2015) through their study point out that flipped classroom approaches remove the traditional transmissive lecture and replace it with active in-class tasks and pre-/post-class work. As evident, use of ICT lay in the very heart of such a set up. With the increasing pressure for higher education institutions to undergo transformation, education being seen as needing to adapt in ways that meet the conceptual needs of our time. O'Flaherty, Phillips, Karanicolas, Snelling, and Winning (2015) have tried to provide a scoping view of flipped classrooms in higher education. The results indicate that there is much indirect evidence emerging of improved academic performance and student and staff satisfaction with the flipped approach, but a paucity of conclusive evidence that it contributes to building lifelong learning and other 21st century skills in undergraduate and postgraduate education.

The Indian situation is very different; we seem to be currently in a phase of transition marked by shifting from one medium to another. Apart from concerns such as availability of resources, technological literacy and implementation hurdles, there is a need to investigate the attitudinal association of teachers with ICT. This is crucial, because it will not just guide the implementation of ICT use, but also will play a bigger role in determining its future trajectory. The thrust towards ICT has gained governmental support with 11^{th} and 12^{th} five-year plans. More popularly, the emphasis has been on school level. However, I wish to explore its presence and meaning at tertiary level, and limit myself to the perception and use of ICT among undergraduate college teachers. The inclusion of ICT does involve complex issues at every stage. Mere implementation is not the concern, however, its impact during teaching-learning process–transition from one medium to another does involve aspects which need to be investigated. For this purpose, I have made a preliminary attempt to understand the working meaning and use of ICT from tertiary level science teachers' perspectives. I have limited my analysis to 4 major questions to teachers which reveal the impact and extend of ICT use. These are:

1. What methods do they presently use in class?
2. Are their methods sufficient and efficient for learning?
3. Do they foresee technology playing a role in the classroom?
4. Has the way students learn changed with intervention of technology in almost every aspect of life?

Methodology

Participants for the study consisted of 15 (2 female and 13 male) science teachers (7 physics, 4 chemistry and 4 biology teachers) in the age group of 35-45 years. All of them were PhDs with post-doctoral research and teaching experience ranging from 5-15 years. All of them were well versed with digital technologies academically. Participants were selected from an institute of higher education in the state of Odisha from India. The institute is funded by the central government. Undergraduate as well as postgraduate courses are conducted in sciences in the institute. To understand the teachers' perspectives, semi-structured interviews were conducted with them, which were audio recorded. Interviews were then transcribed and analysed thematically. Teachers were duly informed about the research and their consent was taken before recording data.

Data & Analysis

The participants have been referred to as T1, T2, T3... T15. Data has been analysed and presented below thematically.

Present methods of teaching

All participants showed their preference for, and primarily used blackboard and chalk for teaching-learning process.

Most (70 %) of the teachers expressed that 50 % - 70 % of their teaching time is spent in lecturing or teacher talk, and rest of the time in problem solving in the form of class task as a part of the lecture.

Some of them explained the process they adopted while teaching. T8 expressed that she provided an outline of the course before the class. T2 said that he spent the first few minutes in revising the previous class, then provided a plan for the present class and subsequently, moved on with teaching the contents mostly using blackboard. T11 and T9 also provided learners some cues in the form of some steps of the problem and then asked them to ascertain the next step. T11 expressed three reasons for this exercise. Firstly, it helped "*to bring the logic in abstract form into something very concrete*"; secondly, it made the class more interactive and finally, it gave the teacher a feedback of the track students are adopting in their logic or problem solving.

T1, T12 and T6 undertook some activities in the class for demonstrations (e.g. balloon and comb to show static charging), at times. For the practical part of science classes, 20 % of the teachers allowed learners to use their computers for recording data and plotting graphs.

33 % participants said that they tried using technology in their classes in some form. Out of them only T4 and T5 used it in the form of PowerPoint (Microsoft) presentations, mostly to show diagrams, which were elaborate, or some experimental images (mostly static). T7 used it rarely to show the pictorial representation of the mathematical expressions, and T9 often gave assignments to use the simulations for understanding the pictorial representations of the mathematical expressions. It was interesting to find that T10 used Google Drive for submission of assignments, in order to make the whole exercise paperless.

Sufficiency and efficiency of the present methods of teaching

Most of the teachers (70 %) said that their method of teaching specifically using the blackboard is efficient. Some of the reasons cited by them are as follows:

a. Worldwide, blackboard is used.
b. Old techniques are the best techniques.
c. "*When you are writing something or deriving with pencil, students will be able to remember, but with PPT etc. students will forget everything in a fraction of a second*". "*Blackboard teaching is very convincing... you can repeat many times... you can take pauses to think*"
d. The amount of content to be written/shown is in the control of the teacher
e. Blackboard teaching gives a better connect with students
f. Content can be explained in many ways

However, 30 % of teachers showed dissatisfaction with their methods. Both T11 and T2 expressed lack of interaction as one reason. T11 said, "*I am not getting enough interaction from the students. It gets very difficult to understand whether they have followed my classes or not by just looking at their face."* He further pointed out, *"assignments and tests don't always help because students might be discussing amongst themselves*". He argued that the increasing class size over the years has made it difficult for teachers to give individual attention, and further expressed that "*the spectrum (of intelligence) becomes wider and very difficult for me to pitch at the correct level. That is really unsatisfactory for me*."

T2 mentioned that if exam results are taken as a marker, then the result is usually at the lower end, for which he was not satisfied. The reasons, he mentioned were the lack of proper mathematical background of students (for physics courses), since the institute had a mixed entry where students with or without mathematics at +2 level entered the undergraduate course. Another reason, according to him, was lack of enough effort and time put in by students.

Many teachers expressed that the methods they adopted for teaching-learning might not be sufficient for the students. T6 thought that if detailed plans are provided in the beginning of the course, then it could be helpful. Another teacher (T13) was concerned that the large amount of material available on the internet results in increased students' absenteeism. He elaborated that only 20 % students are regular, while the others are irregular mostly because they get all the material online (like lectures by famous teachers) and do not feel a need to attend classes. Their results are accordingly low, as compared to the students who are regular in class. Hence, these students might need something more from the class, but he could not provide any solution for this problem.

T10 had found that in one of his courses, students seemed to have lost comprehension somewhere in between the course. On investigating the cause, he found his own teaching method to be inefficient. He would leave few steps in the usual derivation for the students to complete, assuming the students would be able to fill the blanks. However, the students did not find the steps to be obvious, and consequently could not comprehend the concept.

Role of technology in the classroom

Teachers held varied perspectives on the role of technology, which are categorised in 3 major trends: learning (40 %), depends on course (54 %) and no role (6 %). Many teachers felt that technology could be helpful and assist in learning. For instance, T1 said that if pictorial representations of mathematical expressions are presented using presentation slides, it can lead to better comprehension. T5, T8 and T10 emphasized that pictorial representation in 3D, specifically in biology courses, which needs elaborate diagrams using PowerPoint presentations could help improve visualization.

T1 and T7 expressed that technology could be useful in learning the dynamic aspect of systems. T7 emphasised that it could help in letting students experiment with the data – as to how an expression changes if one parameter changes. For that, students had to learn a bit of programming. He often saw initial reluctance in students to learn this, however if motivated and pushed a bit, they could benefit a lot from this practice. T1 demonstrated the dynamic aspect of systems a few times in the class with his laptop and found students enjoying the activity. However, he could not make it a regular practice, since carrying a laptop for every class was cumbersome.

T3 expressed that nature of course decides whether technology can be helpful. He said, "for *courses such as classical mechanics or electronics teacher can demonstrate problem solving through software and ask students to solve rest of the problems*. *It will save time; probably five problems can be solved in the time we spend on solving one problem in the class"*. Also, if there is software which could instantly record the data for an experiment, then the class time can be spent in asking students to explain the data rather than collecting data. However, for theoretical courses like in quantum mechanics (QM) and mathematical methods, blackboard is a must. T2 and T10 emphasised that computers could be useful only for basic level courses, but the higher levels cannot be taught without blackboards. T2 said if all the students had an interactive screen while the teacher taught, it could help in enhancing the interest of students and engaging them, as a lot of students just sit in the class without writing any notes. T5 expressed "*for monitoring what students are doing (i.e. if possible), so that he knows what each student is doing in the notebook and weaker students could be addressed with this*". He found the class size to be large to monitor otherwise, T6 said that a PowerPoint presentation could be effective for the teachers in terms of amount of courses taught and the convenience in keeping the notes. However, he thinks that it is a distraction for students.

T4 had a contrasting view and said "*I use simple boards and white chalks not even coloured and I am very happy with that as well as students are also very happy with that. No change is required and no* *technology is needed in the classroom*."

Future classrooms

50 % of the teachers showed the willingness to have demonstrations in the classroom even during theory courses. In this regard, T1 imagined a classroom "*like classroom–cum–lab where at least, for the first 2 years of the undergraduate courses, you can give some demonstrations. Physics is after all an experimental subject; you need to know what is going on in real systems*."

On probing further with regard to virtual systems, he said for subjects such as QM "*if virtual systems can depict, say scattering of particles, how the two wave packets are colliding, what are the changes they are undergoing as far as the momentum and positions are concerned, that will be wonderful*." Likewise, T6 expressed the need for computer simulations "*where you can really show how a particle enters the system and what happens to it when it comes out.*"

20 % participants expressed the level of course playing the role in deciding the type of classroom. T2 and T14 said not much technology is required for advanced level courses. At times, may be a few videos along with traditional classroom is good enough. T2 mentioned that for first year undergraduate courses, technology could make things interesting and enhance students' involvement. He imagines the classroom with interactive screens for each student and something to support volume, since classrooms are big (1: 130).

T3 showed satisfaction with the present kind of classroom with blackboards, however, for large classrooms, in addition to blackboard, big screens and sophisticated sound systems could be helpful.

T15 opined that we need both blackboard as well as PowerPoint presentations as per the need of the topic.

Changes in outcomes

Most teachers (almost 70 %) expressed that the results of the students would improve with incorporation of technology in the class by adopting specific methods, which they suggested.

T1 felt that students will have "*better grasp on the subject so that they can visualize what they are talking about, their understanding would improve. However, in exams their results might or might not improve."*

T2 emphasised that students' interest would certainly improve, which will induce more involvement and consequently, the results are expected to improve. T3 opined that the attention level of student would go up when we use screen projections and proper audio system, and that it would possibly improve the examination scores.

T5 raised a point that with online monitoring systems, the weaker students who do not participate in the class could be identified, and subsequently their difficulties may be addressed. Their interaction level within the class as well as outside the class may increase. Consequently, he hoped that outcomes in terms of marks would also improve.

T6 on the other hand said, *"students' outcomes depend on how a teacher is teaching, his depth of knowledge and vision. If a teacher can relate the concept to some interesting fact which might be* *useful for students in future, then it will be helpful".* He expressed the need to have more resources for individual engagement for the students rather than technology, and elaborated on the example of a US classroom where he had an experience of teaching for a few years. He exemplified that for an experiment on pendulum, if there are 30 students then there will be 30 apparatus and their understanding is much better. In India, we rarely have so many instruments.

Has the way of learning changed?

Most (almost 80 %) participants agreed that the way students learn has changed. However, the interpretations about this 'change' varied among teachers.

T2 mentioned that general attitude of the students has changed, they do not write notes because there is a lot of learning material available online. The need for the classroom in students' minds is reducing. He saw this as a part of social evolution, and felt that in future, there might not be a need for usual classrooms for first and second year undergraduate students. On the other hand, the teacher needs to see the student face to face so as to understand what they are making out of the course. According to him, this cannot be executed online.

According to T3 and T6, accessibility to academic resources had improved with technology. T6 cited an example that "*if there is a good seminar going in MIT, they can attend from their room itself". Interaction has become much easier and faster. He mentioned that he guides students in India from CERN (Switzerland). Students only need to utilize the technology intelligently rather than only playing video games."* T3 mentioned that with easy accessibility, students can see how different people think on the same topic, and choose the best way to understand for themselves.

T4 had an opposing view. He said smartphones and smart things are actually damaging students' minds. Students use unfair means and copy the answers from the internet. Even in exam, mobiles are being used for copying answers. He further emphasised that books are the best resources for learning, but also agreed that accessibility to e-books and e-journals is very essential when handling hardcopies can often be cumbersome. He said that he uses Youtube based video lectures at times to confirm some facts. However, he did not find any need to take the videos to the classroom for learners. According to him, students do not use technology for any academic purpose; they mostly use it for playing video games, which is detrimental for their development. The respect for teachers has reduced amongst learners as a consequence of their exposure to practices across the globe.

According to T15, with the advent of technology, students have started reading and writing less. Bright students are benefitting from technology, and weaker students are becoming still weaker academically because of reduced reading and writing. Thus, the gap between academically weaker and brighter students has widened. He said teachers need to motivate learners for engaging in class.

Summary & Conclusions

Most teachers preferred using blackboard for teaching- learning in the classroom, specifically for advanced level courses, as it provided them more control and flexibility. They also felt that the time which the teacher takes to write on the board is needed for the students to comprehend the concept. Most of them viewed technology primarily in the form of PowerPoint presentations. They felt that it reduces flexibility and control on the teaching-learning process, essentially due to the fact that the content is usually too much for learners to grasp with increased speed. However, a few of them mentioned that slides give them the scope to enhance some pictorial representations, and thus they are convenient and time-saving for showing elaborate and complicated diagrams (biology and physics) and equations (chemistry).

Some of them conceived a future classroom with technology in the form of projectors, interactive screens, sound system and simulations, but mostly limited to teaching-learning at first-year and second-year courses. For higher levels, they found traditional classrooms sufficient and efficient. Others suggested provision of demonstrations and experiments with theory classes. A small fraction of participants who suggested changes in the classroom also expressed that students' engagement and involvement might increase by use of technology, which could have a direct impact on their academic performance. One of the teachers mentioned that in case we have to introduce technology in the classroom, pedagogy has to change as the present methods of teaching and learning will not be effective.

Most of the teachers agreed that with ICT, accessibility to academic resources has increased. However, many of them were of the opinion that the students do not use it for academic purposes and therefore, it is not much effective for their learning.

In conclusion, technology has changed our lives in multiple ways, and has now become an integral part of our lives. The Indian Government has also invested significantly in bringing technology to classroom in their 11th and 12th five-year plan. However, teachers' perspectives depict a very superficial inclusion of it in the classroom. Most of them considered only PowerPoint presentations as the technology which could be a part of the classroom teaching-learning, whereas there are many other resources available and a some of them are even free-of-cost. Thus, there is still a need to explore the potential of technology in teaching-learning. Implementation of the policy also requires an attitudinal shift in teachers along with creating forums to share various ways in which technology could enhance learning. At the same time, technology should be critically viewed and not used for the sake of it. It will be effective only when used meaningfully, which calls for comprehensive research in this direction.

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ASTRONOMY EDUCATION: A CASE FOR BLENDED LEARNING

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This paper presents an innovative blended pedagogy for teaching high school astronomy as well as preliminary observations on its pilot classroom trial. Astronomy is an essential component of school science. But astronomy is prone to alternative conceptions (Lelliott & Rollnick, 2009). A baseline survey conducted by the Connected Learning Initiative (CLIx) in four Indian states supports this claim. In response to this, we are designing a short pedagogic sequence to teach astronomy at Grade 8 or 9. The astronomy module will comprise 12 lessons, of which, nine are classroom lessons and three are digital lessons. Visuospatial thinking plays a crucial role in learning science (Gilbert, 2005) in general and astronomy in particular (Padalkar & Ramadas, 2010). The astronomy module focuses on building students' understanding using diagrams, role-plays (during classroom lessons) and digital activities, each complementing the other. A pilot trial of one classroom lesson followed by a digital lesson based on the same content (rotation of the Earth) was conducted at a Marathi medium school in Pune with 40 students of Grade 8. The observations at this trial and the way they helped to improve the module are included in this report.

Introduction

Basic astronomy is included in most middle and high school curricula. The syllabus typically explains commonplace phenomena such as day and night, the seasons, the phases of the Moon and eclipses based on the heliocentric model of the solar system. It also gives a brief introduction to planets and other objects in the solar system. Despite devoting a couple of chapters to this topic in school every year and astronomy being a subject of common interest among adults, it is well documented that students and adults carry many alternative conceptions (Lelliott & Rollnick, 2009). The roots of these alternative conceptions can be traced back to the inability to use visuospatial thinking (Subramaniam & Padalkar, 2009; Padalkar & Ramadas, 2010).

Learning visuospatial thinking requires students to visualize a model and simulate it to explain the phenomena being observed. Naturally, most textbooks use diagrams and text to illustrate the spatial aspects (e.g. orbits) of the solar system. Concrete models and gestures (referred to as role-plays in this paper) have been argued to be useful tools to enable visuospatial thinking in astronomy (Padalkar & Ramadas, 2010, Crowder, 1996). Equations are often used in advanced astronomy, but they are not useful for school students since students are not familiar with calculus yet. As educational technology became available, it has been used to teach astronomy in different forms like, Planetaria (Plummer, 2009; Plummer et al, 2014), Virtual reality environments to introduce solar system (Chen, 2007), computer simulations, computation, videos and photographs, games etc.

(The authors are not aware of a systematic study on the usage of the last four modalities in the list to teach astronomy.)

In order to learn science, students must master multiple representations and develop representational competence (Kozma & Russell, 1997; Padalkar & Hegarty, 2015). It is advantageous to use multiple representations to help students construct richer and more accurate models of reality. Exposure to single representations may result in students believing that reality is the same as the representation (Treagust & Chittleborough, 2001). In this paper, we present a short pedagogic sequence in which we blend the different physical and digital representations to teach basic astronomy.

Significance

This study is part of a large-scale field action project called the Connected Learning Initiative (CLIx). The project is mainly meant for government schools which serve educationally disadvantaged students, mostly from rural settings. Developing exemplar educational material for Grades 8, 9 and 11 for science, mathematics and English is one of the mandates of this project. Corresponding material for teachers on how to use this material in the classroom is also being developed simultaneously.

As part of needs assessment, CLIx conducted a baseline survey in four Indian states (Telangana, Rajasthan, Mizoram and Chhattisgarh) in 2016. The survey included questions like the following in the area of astronomy:

Phases of the moon are caused because:

1. something covers the moon

2. the earth's shadow falls on the moon

3. only a part of the lit half of the moon is visible from the earth

4. the moon's orbit makes an angle of 5 degrees with the orbit of the earth

Of the 5418 students who attempted this question, fewer than 17% could answer this question correctly (option 3). A little more than 38% chose option 1 (occlusion), a rather primitive alternative conception. More than 23% chose option 2 (earth's shadow) which is documented as the most common alternative conception regarding the phases of the moon (Trumper, 2000). Almost 21% chose option 4: a fact, but not the correct explanation. Note that the percentage of students who chose the correct option is the lowest when compared to the percentage of students who chose each of the other options.

This has also been demonstrated by earlier studies (Padalkar & Ramadas; 2008, Mohapatra, 1991). In response, a short pedagogic sequence (twelve classroom periods) called the 'Basic Astronomy Module' is being developed. This is a blended module in the sense that 3 out of the 12 lessons are planned as digital lessons intended to be attempted by the students in the computer lab. The remaining nine lessons are to be conducted by the teacher in the classroom. The entire module (which includes lesson plans of all 12 lessons) in three languages (English, Hindi and Telugu) is available at: https://staging-clix.tiss.edu/.

Research design

This study follows the 'Design Based Research' (DBR) methodology which encourages an iterative process of creating, trailing and improving learning material.

Unit 1 of the Basic Astronomy Module covers rotation and revolution of the Earth and the related observable phenomena such as the apparent motion of the Sun and stars, the occurrence of seasons and the changes in the night sky over the year. Of the three lessons in Unit 1, one is a digital lesson.

In the present study, we focused on rotation of the Earth and its consequences. Along with concrete models, role-plays and diagrams, we wanted students to use animations and interactive exercises. We first defined the learning objectives of the classroom and the digital activities. We created a paper prototype and tested it with a few adults, including experts in game design and astronomy as well as lay people. However, we could not test the paper prototype with students. The prototype became the basis for the design of the digital activity. While designing the digital activity, we discussed the sound effects, various kinds of representations, screen layout and so on keeping in mind learning objectives, hardware availability, usability basics and other similar considerations. For example, we decided against adding sound effects because this would require additional hardware and make the file size bigger. After the logic of the activity was thought through, we scripted it providing detailed instructions on screen layout, screen elements and their functions, instructions for interacting with the screen, and the feedback for every interaction. The graphics and technical experts developed and shared the activity with the team and then made changes based on feedback provided by the team.

We conducted one classroom lesson and one digital lesson each in an urban co-educational Marathi medium school. About 40 students of Grade 8 participated in the trial. The digital lesson was conducted in two batches six days after the classroom session so that every student could complete the digital activity individually. Both authors noted their observations and conducted informal interviews with the students after the digital lesson. The digital lesson is currently being modified based on the authors' observations as well as the feedback from students and teachers.

Description of the innovation

As mentioned earlier, the trial comprised one classroom lesson and one digital lesson each.

The classroom lesson started with a discussion on the differences between the real Earth and the globe. This was to emphasize that the globe is only a representation and thus has limitations. Some of the interesting differences pointed out by students were: (i) the gravitational pull of the globe is negligible as compared to that of the real earth. (ii) The real earth is solid where as the globe is usually hollow. This discussion was followed by the following three activities:

1. **Outdoor activity using a Geosynchron** (Monteiro et al, 2008): When the axis of a globe is aligned to the Earth's axis, it is called geosynchron. First students erected human beings (matchsticks) with the help of kneaded dough on different locations on the Earth to learn that the direction towards the centre

of the Earth is down and the radially outward direction is up. There are no absolute up and down directions in space. Then the globe was held in such a way that our location (India) was at the top of the globe so that students could observe that the time of the day and the direction of the shadows was exactly the same on both the geosynchron and the real Earth. Then by slowly simulating the motion of the Earth, they could observe how the local time changes at different locations on the Earth, how day turn into night and vice versa. During this activity, students learnt the right hand thumb rule to determine the direction of the rotation of the Earth (when you align the thumb of the right hand with the axis, with the thumb pointing towards North, the curl of the fingers gives the direction of the rotation).

2. **Role-play to learn about day and night:** In this activity, the students stood in pairs; one student played the Sun and the other the Earth. Students were asked to imagine that four people were standing on the Earth, that is, the head of the student (one on the nose, two on the ears and one on the back of the head) and asked to identify the time of the day for each of these people. Then, the Earth was asked to rotate 90 degrees, and students repeated the exercise. This procedure was repeated thrice over so that the Earth completed one rotation. We encouraged students to use the right hand thumb rule to identify the direction of rotation.

3. **Role-play to learn about the apparent motion of the stars:** For this activity, we directed students to form groups of six. In each group, one student played the role of the Earth, another played the role of the Sun and the remaining students played the stars. The stars stood surrounding the Sun and the Earth. When the student who was the Earth turned around or rotated, she could see how different stars became visible at different positions at different times and how they appeared to move.

Gesture to learn the fixed position of the Pole star: Here, each student fixed an object or a mark overhead and rotated or turned around himself or herself in the anti-clockwise direction to notice that the point exactly overhead does not appear to move.

All four activities were accompanied by question-answer sessions and discussions with students. For more details on classroom lessons see pedagogy documented in Padalkar and Ramadas (2010).

Digital lesson

The digital activities build upon the role play and gestures which they learned during the classroom lesson. It starts with realistic animations which help students visualize the dynamic aspect of the model; then these animations morph into the two-dimensional diagrams students see in their textbooks; finally students test their own learning in the safe, non-threatening environment of the digital activities (games), which also serve as engaging learning reinforcements. The digital lesson incorporates the following two activities:

1. Animation: The animation begins with a view of the realistic Earth (with oceans and continents shown in different colours as shown in Figure 1a) rotating and then slowly transforming into a conventional two-dimensional diagram of the Earth (Figure 1b). Diagrams can be easily generated and transformed and, hence, are very commonly used in learning/teaching phenomena in science. Interpreting diagrams and being able to use them to communicate and solve problems is one of the essential skills in science (Ainsworth, 2011). However, because of their static two-dimensional nature, students often find it difficult to visualise the real phenomenon (Mishra, 1999). The current activity was designed to address this difficulty. If students can see the realistic Earth transforming into a diagram, we hope that they will be able to comprehend what the diagram stands for.

In addition, the animation presents the rotation of the Earth as seen from three different perspectives: from above the North pole (the North polar view), from above the equator (the equatorial view), and from a position between these two (the oblique view). The thumbnails of each view are provided on the screen (see Figure 1) and each animation plays out when the student clicks on the thumbnail. Presenting the rotation from these three different perspectives emphasizes the three-dimensional nature of the Earth, and we believe, it will help students to construct a three-dimensional mental model.

2. Interactive digital activity: This activity was designed to serve as revision of what students had learned during the classroom lesson. Applying knowledge to solve problems is an important step in mastering content. The built-in feedback mechanism in the digital medium allows students to solve problems independently.

In this activity, the activity screen was divided into two sections. The problem was presented on the left side and students were expected to interact with this part of the screen. Here we presented the North polar view of the earth. The feedback appeared on the right side of the screen and used the equatorial view of the Earth. We used these two different views so that students actively coordinated between two perspectives as they solved the problem and interpreted the feedback[1]. On the left screen, stick figures of four children (Sonu, Manu, Guddu and Chhotu) were shown standing at different locations on the Earth (see Figure 2a). The purpose of this activity was to reinforce the concept of how rotation determines time of day or night in different locations. Each problem required students to ensure that one of the four stick figures was at a certain indicated time of the day. To do this, students had to rotate the Earth using the mouse and bring the stick figure to the correct position. After clicking 'Check Answer', students would be shown a visual feedback if they answered correctly or allowed to try again if they made a mistake. Keeping in mind the fact that government schools typically have a limited number of computers for students' use, we assumed that two students will use one computer terminal to complete the digital activities. This provides scope for students to collaborate.

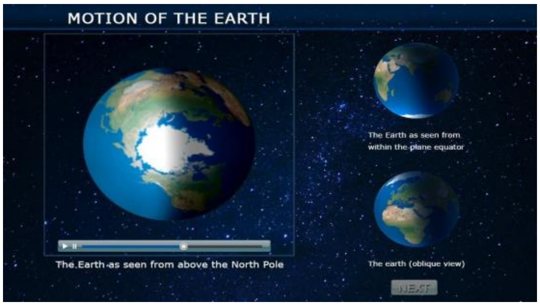

Figure 1a: Realistic representation of the Earth at the beginning of the animation

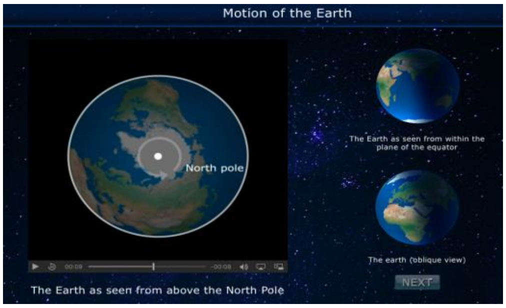

Figure 1b: Transforming from a realistic to diagrammatic representation of the Earth

1 For the sake of simplicity, the axis of rotation is considered to be perpendicular to direction of the sun rays. The angle between the axis and the ecliptic is introduced at a later point.

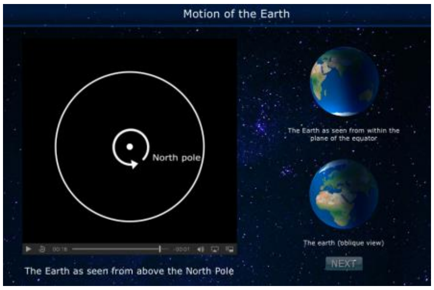

Figure 1c: Diagrammatic representation of the Earth at the end of the animation

Figure 1: Screenshots of the animation of the Earth (North Polar view) transforming from a realistic, dynamic representation to a diagrammatic representation.

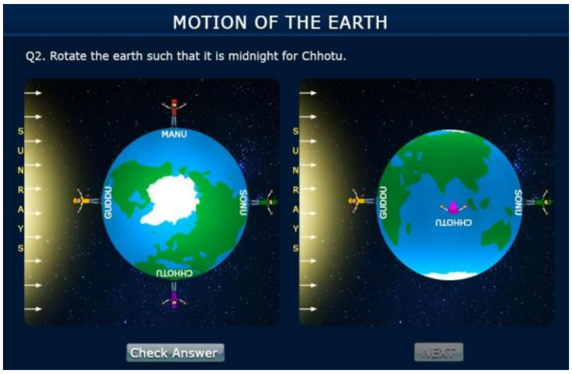

Figure 2a: Problem situation in interactive digital activity

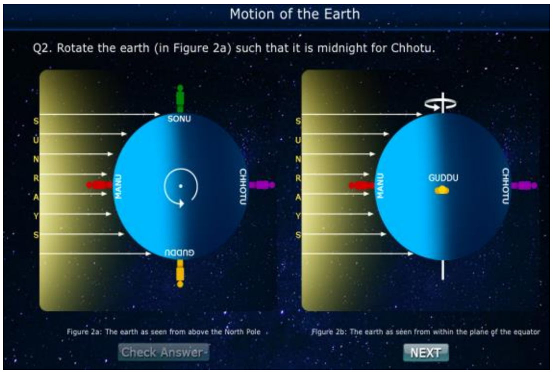

Figure 2b: Feedback situation in the interactive digital activity.

Figure 2: Screenshots of the interactive digital activity.

Observations & Findings

During the pilot, we made several observations, which we subsequently used to revise the digital activity. Some glitches were technical in nature (e.g. the activity did not run on certain browsers). Some problems arose due to minor errors in designing. We are addressing such errors, but we record here the more important observations and learnings:

1. Students were comfortable with the new representations: In the digital lesson, the students were exposed to two visual representations of the Earth simultaneously: the North polar view to present the problem situation and the equatorial view to present the feedback. Both these views were new to students. But during informal interviews, we found they were comfortable with these representations and were able to identify each perspective correctly.

2. Lack of instructional text: We had kept few instructions on the screen in order to minimize the text on each screen. For example, in the first digital activity the thumbnails for simulations from different perspectives were presented on screen, but there was no instruction directing students to click on each of them one after another. We found that students automatically explored the screen and figured out what to do, while adult users asked for instructions. This behavior could be explained by the difference between digital natives and digital immigrants (Prensky, 2001). The children in the present sample were from educated urban families; so it was not surprising that they were able to navigate on their own. However, our intended students do not have much exposure to technology and neither do their teachers. So, to be on safe side, we decided to add instructional text in the revised version.
3. Lack of text feedback: In the digital activity, when students rotated the Earth more than required, there was no way to undo the action by rotating backwards (since the earth rotates only in one direction). When students clicked 'Check Answer', the stick figures jumped back to their original position so the students could attempt the activity again. But it was not obvious to students that they could try again. We, therefore, decided to add specific text feedback at such points.
4. Lack of context to the problem situations: During the classroom session that involved the geosynchron activity and the first role-play, students were asked to find particular time of the day for a person at a particular location. Students were engaged and enjoyed figuring out where a person would be if, for example, the Sun was setting for her. However, during the digital activity they seemed a little uninterested. This could be because they had already learned the principle behind it. The digital activity then only serves as opportunity for practice. In order to keep students engaged in the activity, we are now developing a game on the lines of a treasure hunt, wherein students have to rotate the Earth so that it is a certain time at a certain location to collect the treasure. There is no time limit, but the number of attempts and the total time available to play this game are fixed. So students who are quick and accurate will be able to collect more treasure than the students who are slow or have not understood the concept.
5. Integrating representations: In the classroom activities, we encouraged students to draw parallels between concrete models and role-play. In the first digital activity, we actively integrated two kinds of representations: three dimensional animations with their corresponding diagrams. In the second digital activity, we came across instances of students spontaneously integrating representations from the classroom session with the digital simulations. For example, while solving a problem in the second digital activity a student used the right hand thumb rule to determine the direction of rotation of the Earth. We consider this a success because students not only mastered the content but seem to have developed some representational competence.

Conclusion & Discussion

Teaching and learning material of any kind needs to be carefully designed and tested for its appropriateness (Sarangapani, 2016). This is especially true for digital tools because, first, the users have little control over them, and so they cannot modify the tools and second, the process of creating digital tools is complex and costly. So unlike printed material, in which content can be revised in every edition, it is difficult to rectify the mistakes in interactive digital material.

In this paper, we have spelt out the process of creating digital resources. Here are the important insights we gained during the process of creating digital tools:

1. Digital resources must be designed keeping in mind the overall learning context. They need to be seen as part of a larger pedagogic sequence rather than an independent resource and hence should echo the learning objectives of the classroom activities. Needless to say, like any teaching resource, digital resources must be appropriate to students' age and sociocultural background.

2. Continuous trialing with different samples should be part of the creative process. The difficulty faced by or a strategy used by even a single participant can be enlightening.

3. To avoid the possibility of getting carried away with novel, interesting features of the digital medium at the expense of effective pedagogy, well-defined learning objectives should be clearly spelt out and used as a guide for development of the material.

Future directions

The supplementary material for teachers is being prepared and will be part of the Open EdX course for in-service teachers offered by TISS. It includes videos of role-plays and activities, notes on pedagogic significance of the activities and some extra information on astronomy. The rollout of the module is being planned in late November in Rajasthan. We will study how students and teachers receive the module by closely following three to five teachers.

Acknowledgements

We are thankful to the teachers, students and administration of Aksharnandan school for allowing us to conduct the trial. We acknowledge the invaluable contributions of Archana Correa, Jaya Mahale, Jayashree Anand, Judith Perry, Louisa Rohenseck and Scot Osterweil for their support in module development; Somendra Tripathi and Vinaya Tripathi for their technical support; Anusha Gajinkar and Archana Mehendale for providing us the data from baseline survey and Shiva Thorat for video shooting (names appear in alphabetic order).

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PROBING 'DESIGN THINKING' THROUGH SIMULATION TASKS: A NOVEL TOOL TO ELICIT THINKING STRATEGIES AND PRINCIPLES IN GRASSROOTS ENGINEERING DESIGN

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We study the design of technical artifacts (such as micro hydro turbines) by grassroots innovators, who are not formally trained in engineering. Much of the data are based on the designers' memory of installations. While these give a sense of their design practice, it is not possible to get insight into their mental models of electricity and its generation (process), as well as the design process behind the various components of a micro hydro power system. Also, this method does not allow systematic comparison of their design process with the process of formally trained innovators who work on similar problems in rural areas. An actualized system, where the rural innovator and the formally trained innovator both design using simulated components, would help in probing their mental models in detail and elicit rich qualitative data. To examine this possibility, we designed a (virtual) simulation tool that offered the designers specific (and same) problem situations, allowing them to comment on the virtual task against the background of their real world experiences. In this paper, we report the design of this research tool, and our analysis of the data generated from its use.

Introduction

The interdisciplinary nature of the sustainability challenges and neglected needs of marginalized people at the grassroots make these problems highly complex. A critical component of the new approach to engineering education is the understanding of the design process, and the role of cognition in design practice. David Craig considers design as “any problem solving activity that results in the creation of an artifact or a plan for generating an artifact” (Craig, 2001, p14). According to the standards for technological literacy: content for the study of technology by international technology education association (2003), ‘design' is ‘the core problem-solving process of technological development. It is as fundamental to technology as inquiry is to science and reading is to language arts.' Design is an activity common to all engineering disciplines, and Jonassen classifies design problems as “typically the most complex and ill-structured of all problems” (Jonassen, 2014).

Some such problems are addressed by formally and non-formally trained technology designers. In this paper, we present a part of our study of the problem-solving / designing thinking involved in one such grassroots technology design: that of micro hydro power systems. The larger study comprises of the characterization of design process, thinking, and mental models in grassroots design, through case studies of the design practice of i) a formally trained engineer, ii) an undergraduate engineering student, and iii) a non-trained grassroots innovator.

The designers have designed and built micro hydro systems to generate power in the range of 50 W - 100 KW. They work in geographic regions deprived of reliable and affordable power supply, but rich in gradient and/or perennial water supply. Across these designs, many aspects of the problem, such as the socio-cultural, economic, and political context, are very diverse. The designers themselves bring distinct backgrounds and relationship with the context to the problem. The undergraduate engineering students work in a limited learning context.

An understanding of the grassroots design thinking is hoped to offer take away for engineering education, where reforms are called for to bring in better student engagement with the society and its real-world problems.

Towards this end, we want to probe:

1. What is the nature of the designers' understanding of the 'problem' i.e. the 'requirement' for power in its specific site context.

2. What can be said about their design goal/principles on the basis of how they go about distributing the power generated from the given site conditions?

3. What is their understanding of the relation between the site parameters and generation of power i.e. the conceptual / mental model* of hydro power generation? (*: The mind constructs "small-scale models" of reality to anticipate events, to reason, and to underlie explanation. (Craik, 1943).)

4. What is the role of experience and theory in their design? What kind of estimations and calculations do they perform? What systematic methods do they use for these?

Limitations of earlier data

Following the case study method (Yin, 2003), we collected data through semi-structured interviews, artefact details, photos, and secondary data from reports of installations. While these data give a sense of their design process, they still do not provide sufficient insight into the mental models that lead / enable them to design their (socio-) technical systems for hydro power generation.

Further, as the designers designed their systems over last several years, all the data are historical. Their current running systems are the final designs, and intermediate stages are rarely available. As a result, the process data and progressive design trajectory were only available through interviews. Methodologically, the interview method is limited to memory-based responses, and liable to have erroneous recalls. One way to address this limitation is triangulation, by collecting non-recall data i.e. procedural data through having the designers perform and demonstrate part of their design process in real time. This would also allow us to overcome the imitations that individuals are not always aware of what they think and why they do things the way they do, although they may offer post-facto explanations. Literature warns that such explanations may not necessarily be what the individuals actually thought.

Also to draw out the generic principles guiding design across multiple cases and a diversity of contexts, and to discuss these across designers, we required a common design platform.

Design research studies and methods

In the words of Clive Dym, "...design has come to be viewed as a cognitive activity that can be modelled, so that design research and design itself are now taken much more seriously as legitimate areas of intellectual inquiry." (Dym, 1994). According to Nigel Cross (1984), the early prescriptive design process studies contributed design process models, that did not succeed when empirically applied. The descriptive studies that followed, characterized the nature of design problems (as poorly specified, with vague goals, and ill-defined). This led to studies of designers in experimental settings, and contributed an understanding of a typical design practitioner. This opened more areas of design such as decision-making, and life-cycle models research (Atman et al, 2014).

Practitioners' design thinking and doing

Bryan Lawson (1979) reported experiment-based studies of expert architects and scientists, comparing their problem-solving approaches. Cross (2011) presented interviews with expert engineering designers, exploring their design thinking and process. Jonassen et al (2006) identified that practicing engineers rely primarily on experiential knowledge, and they use multiple forms of problem representation, rarely using equations.

Engineering design research

Engineering design research differs from some other design research in the way it emphasizes the role of scientific and technological knowledge in the domain of engineering. Researchers have investigated the engineering design processes, categorized by Atman et al (2014) as: work, cognitive, and social processes. In order to improve the education of engineering design, researchers have also studied students learning. (Atman et al, 2014; Dym et al, 2003).

Design research methods

According to David Craig (2001), four strategies have been used by researchers to conduct studies in design behavior research, across design disciplines and expertise levels. These are 1) Think-aloud protocols (Eastman, 1969; Akin, 1978; Ullman et al, 1988) used to "illustrate, support, or expand cognitive models of design" as per Craig (2001, p18), 2) Verbal or content analysis focused on knowledge representations used in design (Akin, 1978; Crismond, 1997; Atman et al, 1999), 3) Process isolation studies in design (Akin & akin, 1996; Casakin & Goldschmidt, 1999; Lawson, 1979, Verstijnen et al, 1998) to explore cognitive processes as well as representations, through controlled study of processes isolated from design episodes using simple or miniaturized experimental design tasks, and 4) Situated studies of design, in work (Bucciarelli, 1994; Goel, 1995; Harrison & Minneman, 1996; Schon, 1982) or experimental (Cross & Cross, 1996; Berenton et al, 1996) settings, focused on design activities in their contexts, such as the socio-cultural and material ones, rather than on idealized practices or isolated cognitive processes. "Context, rather, is taken to be constitutive of practice" (Craig, 2001, p29). Craig points out a limitation of the studies, as "Few studies in design deal specifically with how concepts are constructed, reproduced, or conferred through local practices. Most seem to assume that although knowledge may be subjective, it is ultimately derived from experiences via general reasoning (e.g.

inductive generalization or pattern recognition)" (Craig, 2001, p30).

Atman et al (2014) describe five methodologies followed in engineering design education research, while also pointing out that these differ from design research not by the methods used, but rather by the research questions being asked. These are protocol analysis, interviews, surveys, ethnographies and field studies, and analysis of (learning) artefacts (p208-9), for studying product and process design in both experimental and natural settings.

A new data collection tool

Based on the previous research studies and available methods, an experimental design task environment that captured the dynamics of a hydro power system, and allowed for the design scenario to resemble the real world site as much as possible, and for the designer to experience it so, could serve to address the limitations in data collection. Since no such task setting was readily available, we developed a new probing tool with a simulation protocol: a common virtual problem scenario.

The experience of working with a computer-based virtual simulation would be similar for the designers, in terms of being somewhat familiar with computers, and not having come across a simulated hydro power system before. Contrary to a pen-and-paper problem interface where a formally-trained designer may be at an advantage, or a real-world situation, where an experienced designer may be at an advantage, the simulation was a probing interface where none of them was expected to be at a particular advantage or otherwise.

We focused the tool on the embodiment stage of design process, which allows us to provide a concrete and common design space, while at the same time explore its implications with respect to the conceptual and detailed design stages.

Simulation of the design of a micro hydro power system

The simulation presents a virtual problem scenario, and four different design tasks based on it. The scenario shows a waterfall in the mountain, a platform next to it to build the power system, and a small settlement of houses in the valley below.

Figure 1: The simulation interface

The Explore screen allows exploration of the interface, to understand what it affords in terms of designing, and what feedback it provides about the system performance. The tasks involve designing a micro hydro power system, by selecting appropriate components and defining the specifications of some of the components, using water from the waterfall, and supplying power to the settlement. All the houses are assumed to use the same gadgets, which can be specified in the interface. (See Figure 1: The simulation interface).

Simulations tasks

The first two tasks are developed such that only qualitative information is directly available for designing. The simulation depicts the system dynamics through rotation of the turbine wheel, and animation of the water jet and the lit houses.

In contrast, the next two tasks are purely quantitative / numeric, and no sense of the system dynamics is available through animation.

Data collection

The same designers with whom interview data had been collected earlier, were asked to work with the simulation probe. The designers familiarized themselves with the simulation through the Explore screen, and then completed the four tasks. A touchscreen laptop was used, but a mouse and touch pad controls were also provided. This data was logged on the server. An eye-tracker was used to track the designer's eye movements on the laptop screen. The researcher was present to clarify any queries they asked. The designers were free to talk to themselves or the researcher, or to keep quiet. It was not a verbal protocol study. All the designers talked to the researcher while working with simulation, in terms of queries about the controls or functioning, and their comments in the context of the tasks and their real-world design experience. Due to this, the eye-tracking data, recorded as red dots superimposed on a video capture of the screen, was not consistent. There was no time constraint. After completion of the tasks, the researcher asked follow-up interview questions to the designers.

Description and analysis of data

In this paper, we limit ourselves to analyzing the data from simulation interactions (video and data logs), and interviews. While we do have some eye-tracking data, work is still underway to analyze the same. Due to limitations of space, we also restrict the analysis to only one designer's data, based on the themes of system construction, load variation control, power consumption and generation.

GRI's simulation interaction and interview comments

The non-trained grassroots innovator (GRI) explored and imagined the virtual system with reference to his real world contexts, experience, and knowledge of design. Despite this, when working on the simulation tasks, he mostly worked on the basis of the feedback generated by the simulation interface. This is anticipated as there are no real values of parameters or gadget ratings provided in the tasks.

For these reasons, it is important to understand his choices and actions in the simulation with reference to his comments and explanations in the interview that followed. This is particularly important for the numeric tasks 3 and 4.

I) System construction

GRI explored all the components, houses, gadgets, and parameter settings in the simulation in various ways. His first choice of components to design the system was the pipeline, nozzle, turbine and generator. Having found no performance difference in a gear vis-a-vis a pulley, he settled for the pulley. His choice of pulley confirms ease of maintenance for local people as an important design principle for him, in the context of the remote sites where he installs micro hydro power systems. He commented that the nozzle in the animation has a problem, because the water jet looks more like spray, and it will not give good torque.

> "spray... split. It is not completely... not torque... point."

II) Load variation control

GRI did not use the flywheel in all the task situations, and did not actively look for a load control component or a dummy load such as the heating coil. He explained that he uses a flywheel in his system to stabilize the turbine, only if site conditions and requirement composition (such as high amperage gadgets) make it necessary.

> "Sometimes more head is available... flywheel is not required..."

> "And blender. Takes more amperaty. Then flywheel is compulsory. When you use amperaty, definitely use the flywheel."

GRI preferred to design his real-world systems such that when load drops, the excess generated power is diverted to street lights, rather than a heating coil.

> "Below 10KW ... nothing happens. 10-12% varying. After that, when load completely switches off, that will be overproduction. Then you will convert it to dummy load... like heating coil or diversion lights. I will say suggestion… street lights. That's a easy solution."

III) Power consumption

Given the option, he selected the gadgets TV, bulb, and lamp post as the most preferred for his users. His choice of gadgets indicates that he commonly designs for these applications, and is most familiar with them. He did not change the number of houses (12), but he was more comfortable supporting seven rather than five houses in task 2. Based on the uses or needs of his customers in real world, he explained his choice of gadgets.

> "Light is compulsory... fan is occasionally... and blender... TV is very common. Fridge is not compulsory. Only option is lighting and TV… villagers or any householders. First priority this. After you get sufficient power, after then, fan, mixie [blender]... enjoy that. But first.. basic.. light, TV."

He commented that there would be many options to support all the houses and the selected gadgets, and so he did not remove any houses. Thinking in terms of the real-world situation, and not the constraints of the simulation, he explained that lower wattage LED bulbs now being available, could reduce the power required per bulb. He emphasized that in the lean period, he did not want to reduce the number of houses to less that the 12 in the simulation, because it cannot be done in a real village.

> “That's constant. Anybody not compromise... all the... suppose you give [to] one or two houses... other remaining shoot him (he chuckles.)”

> “The requirement is constant. The source is vary. After then we will compromise.”

IV) Power generation

While setting the parameters, GRI varied and set the value of head first, and then the discharge (by varying the nozzle diameter). In the (visual / non-numeric) tasks 1 and 2, he increased values of these parameters to generate more power, when he added more houses, more gadgets, or gadgets consuming more power, and the other way round. His actions in parameter setting reflect his awareness of the correlations between head, discharge, and power generation. He finally set near maximum nozzle diameter, but medium head.

In the (numeric) task 3, when he set the head to 15 m and discharge to 15 lps, the system feedback indicated that he was generating 795 W less than the required 3000 W. GRI assumed the simulated system to be the replica of some real-world system, with certain component specifications, and not an idealized system with 100 % efficiency. He understood the problem situation as: the components of the simulation system are so designed as to generate 2205 W for 15 m head and 15 lps discharge, but he is being asked if he can generate 3 KW instead. He answered that he could change the specifications of the components, and raise the power output not only to 3 KW, but to 5 KW, for the same water availability.

In the (numeric) task 4, for the pre-set head (4 m) and discharge (16.25 lps) values, his answer was that the system would generate 10 KW. (This is more that ten times the theoretical power.) He did not use any equations or explicitly estimate the theoretical power. Instead, he asked for additional technical details, such as the gradient and the diameter of the pipeline.

Task 3 and 4 show that he did not design with any equations, or make any calculations, to arrive at the answers. For him, the numeric task 4 did not make any meaning, and he might have given a random answer. Even though GRI seemed to bring real world context to the virtual system, he did not bring any numeric values of head, discharge and power from his real world sites to tally with the task values. This implies that either he does not think of site conditions in numeric terms (measured in meters and liters per second), and so his sense of head, discharge, and power is so embodied that he cannot bring it to this numeric task. Or he does not think of potential power from a site in terms of head and discharge alone, so he cannot reduce it to those two parameters. GRI commented, with reference to the simulation scenario, on how he designs in real world.

> “By experience. It is not measurement... for e.g. you will calculate by 6 inch pipe, water is available in throughout year… calculate approximately for e.g. it is available 30 feet head... 5 KW. Thumb rule... thumb… means roughly that's it.”

In the context of generating 5 KW in task 3, he explained how he would be able to do so. He would change the component design specifications, so as to i) increase the RPM to the generator through telescoping the pipeline, reducing the size of the turbine wheel, and increasing the pulley ratio, and ii) for the RPM so generated, he would redesign the alternator to generate more power.

> "… increase the RPM very simply… for e.g. this pulley... mostly... I'll just rough calculate... diameter is 12 inches. Decrease... 10 inches will do. Definitely 10% RPM is rise."

This he claimed on the basis of his heuristical knowledge / thumb rules in terms of correlations of component performances and specifications, and possibly a reference system that he designed. He thought of these changes in relative terms, as percentage changes in component specifications, or RPM and power generated, with reference to the numbers assumed in the simulation. To generate more power without more water, he suggested reducing the turbine diameter.

> "Reduce. Must be it is 20%."

Findings about GRI's design thinking and process

This analysis allows us to arrive at some findings about GRI's design thinking and process, beyond what we could from earlier data. These can be summarized as:

I) Problem space formulation in GRI's design process

The simulation data augments previous data in indicating that GRI considers not only technical, but many non-technical factors in formulating the problem space. These factors include both the opportunities and constraints at the site, as well as the need or requirement of end users in terms of power quantity and quality. Furthermore, these factors influence not just generic design decisions but also component-level specifications.

For example, he selects a site where he can get good gradient and a straight pipeline, and also brings the pipeline to within 100 m of the village, to avoid transmission losses. He does not use a heating coil to manage load variation, as the villagers do not know how it works. Instead he diverts excess power to street lighting.

> "… when you use a heating coil, it is very sensitive. In the villages, it is … [to] know about this what is the action or cost… not known. Give more water is very easy... any uneducated man also can do it."

II) GRI's mental model

GRI does not think in terms of theoretical power, with head and discharge being the only two parameters to be designed to generate required power. Rather, he thinks of the entire system, and how he can adjust various components and their specific parameters to together generate the required power. He thinks of hydro power in terms of RPM in the system i.e. as using water flow to generate sufficient RPM in the alternator. Further, he designs all the component specifications, keeping in view the goal of generating RPM, and also thinks of load variation in terms of controlling the RPM rather than controlling voltage variation.

The mental model of the power system includes not only the technical criteria of power generation, but also the socio-technical criteria (such as maintenance in remote areas) that need to be considered in order for the technology to really work for people.

III) GRI's design thinking and knowledge

GRI does not make measurements and calculations based on theory. He is not explicitly guided by the principle of conservation of energy, which dictates that, even assuming 100 % efficiency, more than the theoretical power cannot be generated. He uses many thumb rules developed from experience. He designs by working with the components, and not equations.

This may further indicate that he designs his real-world systems by using one of his early systems as a reference system, using heuristics and thumb rules to revise the specifications of components relative to the reference system. His process/ sequence of design also reflects that he builds on one component to design the next component. For example, the simulation tool uncovered data on how he decides the specifications of the flywheel in tandem with the specifications of the turbine designed for those conditions, based on thumb rules.

> “The inner spokes... very less weight. Outer is completely weight. Central is very less.”

> “For e.g. Pelton wheel thickness is 3 inches… width... flywheel 2 inches.”

His designs are guided by principles of simplicity in design / manufacture / maintenance keeping in mind the site-specific end users and their requirements. “Very simply” or 'keeping it simple' is his motto. By eliminating options that are not necessary for the users, or not possible for the site conditions, he focuses on delivering a feasible and satisfactory solution. This also helps him keep the costs down, and provide on-site, decentralized, accessible power, without creating environmental or systemic problems.

Discussion

In the previous interviews and other data, GRI talked about his design process and historical trajectory of developing his design. Those data did not give insights about the component-level design decisions, and whether and how the context was taken into consideration. Also, it was not clear if GRI had over the years, may be after having engineering students doing internship with him, picked up basic theoretical knowledge and equation-level details of theory. We did not get a sense of whether his design was based on a numeric understanding of the various parameters, or something else.

His simulation actions and comments, enabled us to gain insights on these aspects. Even where the simulation did not offer an opportunity to vary the setting, such as for example the diameter of the turbine, new details related to this became available through his queries and answers to follow-up questions.

Based on all these data together, it is now possible to arrive at a more detailed characterization of GRI's design process, thinking, and mental model of hydro power. He appeared to think and recall specific cases, rather than theoretical abstractions generalized from many cases. While it is not assumed that the designers bring the same design thinking or processes to the virtual simulation tasks / follow-up interviews as their real-world design, the virtual situations helped recall and/or simulate more specific real-world contexts and allowed us to probe for details of their design thinking and process.

Although this paper only discusses one designer, the level of detailed data provided by the simulation across all designers provides us with the opportunity to understand the differences and similarities in their design space formulation, knowledge base and its role in design, and their mental models of hydro power generation. This analysis is ongoing.

Findings about the simulation tool

1. The tool offers certain selected components and gadgets, and some specific details of the site, for the designer to work with. In defining it thus, the problem gets more structured and scoped, compared to the real world situations that these designers handle. In this sense, the tool explores the aspects that the designers now deal with, where they have already firmed up their primary conceptual design, and are no longer designing for a problem completely ill-structured or open-ended. This is so intended, since the simulation tool is required to probe the designer's thinking with these specific components, gadgets and so on, as already mentioned by him in his earlier interviews. As already mentioned, their respective primary conceptual design stages have been explored and are being documented elsewhere.
2. In this basic version, the tool also limits the interactivity to selection of components and gadgets, and varying only two site parameters. It does not allow manipulation of the sizes of the turbine, ratios of the pulleys or gears, or ratings of the generator.
3. Particularly because two of the tasks are visual, and abstain from offering any numeric data on the site parameters or power requirement, the designer needs to work in a 'trial and error' method, to arrive at solutions. While this is intentionally so designed, to explore the non-formal approach to designing, it imposes the limitation of working with the virtual feedback generated by the tool, as real embodied or visual feedback is not available.
4. Going beyond the designer's initial design, the tool tries to uncover the design thinking and the knowledge the designers currently bring to their real-world practice.

Benefits of the tool

1. It is seen that the designers bring their mental models, knowledge, experiences, and design approach to the exploration of the simulation interface. As a result, the interface acts as a good tool to uncover some of the knowledge / biases / thumb rules they bring to their design process. Through the hypotheses they test, the simulation helps reveal their mental models.
2. The tool engages the designer in a virtual design process that simulates some features of the dynamic real world situation. It allows him to perform and demonstrate some parts of his design process in real time for an otherwise extended real world design.

3. The designer's actions provide non-recall data i.e. procedural data, to triangulate with the earlier interview data. It would not be possible to capture this data with a pen-and-paper and/or verbal protocol design study in a lab-based experimental set up.
4. The tool captures data about how the designer works with visual v/s numeric information.It provides a window to explore the kind of knowledge he works with, and how a lack of formal knowledge may get compensated for. Such a comparison of the designer's thinking across visual-dynamic / numeric modes is made easier by the simulation tool.
5. The tool allows us to create specific design situations (tasks), where, by either specifying or controlling some aspects, (for example, in this case the requirement or the site constraints), we gain better insight into how the designer goes about designing for the other aspects.
6. Instead of a verbal hypothetical situation, the simulation interface provides a concrete case to discuss. The designer's action on the tasks provide specific instances of design decisions, such as selection of a component or a gadget, or modification of the requirement.
7. As the tool provides the same tasks, components, and gadgets to all the designers, the data allow for understanding the similarities and differences in the decisions of the different designers given the same situations.

Implications for design research and beyond

1. The simulation tool is a novel and useful probing / data collection approach for design thinking studies. It allows recording designers' design decisions and to identify interesting episodes therein, using standard tasks and questionnaire. It also generates rich qualitative data about specific components and design decisions through follow up questions. Similar simulation probes may prove useful, especially for engineering design studies, where processes or systems are designed often in a modular fashion, extended over time and place, dynamics are involved, and component-level design thinking is to be explored.
2. The simulation was also pilot tested with engineering students who did not design or build any real-world micro hydro power system. Feedback from these students as well as the designers in this study indicates that the simulation can also be a learning tool in the modules of hydraulic turbines and power systems.
3. The simulations also has some limitations in terms of enabling the designers to follow the exact same processes and thinking paths as they do in real world contexts. Particularly, they can only change the head and nozzle parameters, but not the turbine or generator ones. An advanced version of the simulation, based on this data and feedback from the designers would possibly eliminate some of these issues.

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THE CONCEPTUAL GRID METHOD: AN EFFECTIVE APPROACH TO PROBLEM SOLVING IN PHYSICS

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It is well accepted that a strong conceptual base and clarity in understanding are necessary for problem solving. It is also recognised that other allied skills and intuition developed over years through individual experiences play a major role. The ability of a student in problem solving provides an unambiguous and tangible parameter to assess not only the depth of understanding of the concepts, but also his cognitive skills involving the ability to reason and recognise the related concepts. It will therefore be rewarding for a teacher to present an instructional framework which continuously and systematically broadens the conceptual base and enables interconnections of concepts, as against providing conceptual details in an unconnected or detached delivery. Although there is no dissension regarding the importance of problem solving in pedagogy, we see a divergence of opinions in the existing literature about the approach suitable for enhancing students' problem solving abilities. In this study, the need for a systematic instructional framework is addressed through the "Conceptual grid method of problem solving". Conceptual grid is a connectivity map of concepts in a topic of interest; each concept a node in the grid. The effectiveness of this method is studied and reported in this work.

Introduction

The subject of physics, at its fundamental level, spans across various other subjects and sub-disciplines. Lately, it has become imperative on the part of practitioners of various other disciplines to gain some flair in applying physical concepts to a variety of situations (Reif, 1995). Hence, it becomes necessary to foster ample amount of problem solving and analytical skills along with concept learning (Reif, 1981; Maloney, 1994; Kohl & Finkelstein, 2008; Rebello et al, 2007; Van Heuvelen, 1991) during introductory physics courses. However, it is generally observed that a student tends to first search for the relevant concepts and then try to recollect a formula when presented with a problem (Larkin et al, 1980; Chi et al, 1981). If the problem involves more than one concept, then the student has to develop the ability to work with those concepts, sometimes also in parallel, and reach a point of convergence leading to the solution. In this process, the student usually encounters a number of roadblocks which could be, among others, (a) difficulty in clearly identifying the concept/s pertinent to the situation; (b) lack of understanding of the concept pertinent to the situation; (c) lack of competence to apply the concept to solve the problem; (d) lack of analytical skills to navigate to the solution. In the conventional practice, a student is generally presented with a number of randomly chosen problems, without any specific structure evident. This exercise is more often a burden on a student's cognition which may manifest as fear and aversion to problem solving.

A number of techniques have been developed and their utilities have been discussed recently in the literature (Docktor & Mestre, 2014). Some have used computer programs (Reif & Scott, 1999; Dufresne et al, 1992; Mestre et al, 1993) and tools in an attempt to encourage students to recognise the underlying conceptual structure and to make the process of problem solving more rational than just a mundane practice (Kim & Pak, 2002). In a classroom setting, the teacher has the added responsibility of taking the entire class along and therefore has to be sensitive to the requirements of some students who lag behind the majority, and also of those who progress faster than others. The reason for this disparity could be many and it depends on the previous training and tutelage they may have undergone. The design of conceptual grid and its methodology of implementation have resulted in better performance of majority of students and therefore show promising results.

Method and experimental details

The main objective of conceptual grid method is to facilitate students to become familiar with the conceptual environment of a chosen problem. This can be achieved by first creating a set of minimum number of problems spanning over nearly all the concepts in the chosen topic and then by tagging problems to the representative node/s in the conceptual grid besides establishing the possible linkages between the nodes involved. In other words, any new problem should ideally connect to one or more nodes within the conceptual grid of the topic. By this method of learning, a student, when posed with a new problem, can arrive at the solution by navigating through the already familiar environment *viz.*, the conceptual grid. The following mind map gives an overview of the study.

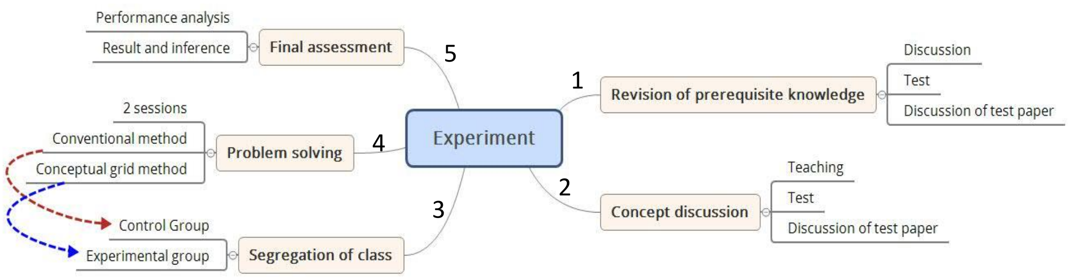


Figure 1: Schematic representation of the study

Review of prerequisite knowledge

The topic of Projectile motion was chosen for the study. To have two groups of equal performance for the study, the following procedure was adopted. A set of 36 students of class XI was picked. To meet the prerequisites, the students were taken through teaching sessions, discussions and tests on the topic of linear motion.

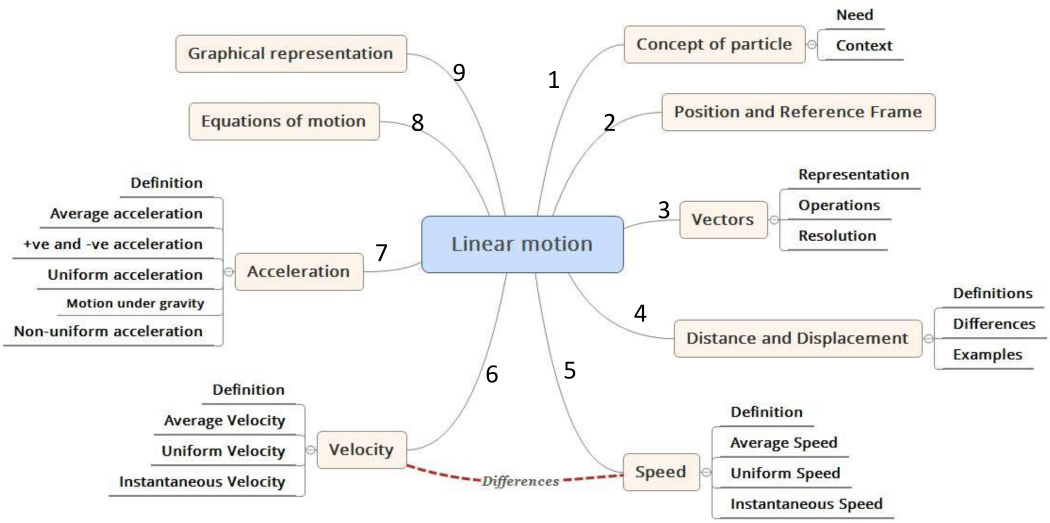


Figure 2: Mindmap of prerequisites

A test was designed to check the ability of the students to comprehend questions, apply the concepts of linear motion and basic level of mathematics to solve problems. The paper consisted of 4 questions: one each on average speed and velocity, uniformly accelerated motion, vector representation and interpretation of linear motion and motion under gravity. Situations involving mathematical difficulty were deliberately avoided and focus was maintained on conceptual navigation, rather than on simplifying equations. None of the problems were of "substitution - calculation" types. The gaps in understanding of the prerequisites in both groups were addressed together in a session to enable level playing field for their study of projectile motion. The results of the test on linear motion was normalised and two groups of equal performance distribution were formed *viz.*, the control and the experimental groups.

Conceptual structure of the domain and discussion

The topic of Projectile Motion was chosen as the domain for the study. The conceptual mindmap of the topic is given below. The domain knowledge was effectively established by way of logical evolution and development of the concepts. A session of 1.5 hours duration was held commonly to experimental and control groups. This session preceded the implementation of conceptual grid method of problem solving.

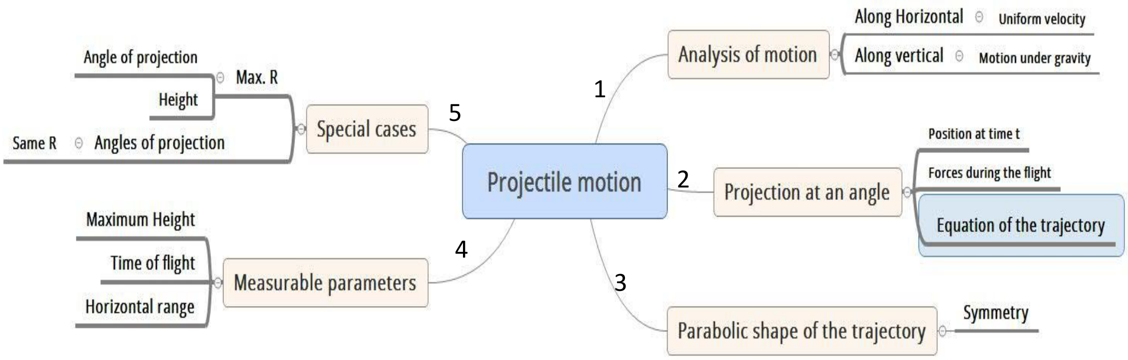


Figure 3: Mind map of projectile motion

The implementation of conceptual grid method

Problem solving session 1

The problem solving session was conducted separately to the control and the experimental groups. Problems on the following concepts were chosen.

- Change in position of the particle along X and Y axes
- Change in velocity of the particle along X and Y axes
- Equation of the trajectory
- Change in the direction of motion with respect to time
- Angle made by position vector and velocity vector with the X-axis at different instants of time
- Exploiting the symmetry of the trajectory to identify

(i) positions at which velocity vectors of equal magnitude and inclination with the X-axis (ii) position at which the velocity vector changes its direction by 90^o.

- Maximum height
- Time taken to reach the maximum height
- Horizontal range

Control group was given a problem set containing representative problems for each of the concepts listed above. The problems were of standard, end of the chapter variety. Students were facilitated to solve the problems in a conventional way with no conscious attempt to bring in the connectivity of concepts amongst the problems. The experimental group was given the same set of problems, however in a form where the conceptual connectivity is implied. In other words, problems were framed with an inbuilt element of conceptual connectivity which was explicitly brought out along with its navigational paths during the discussion.

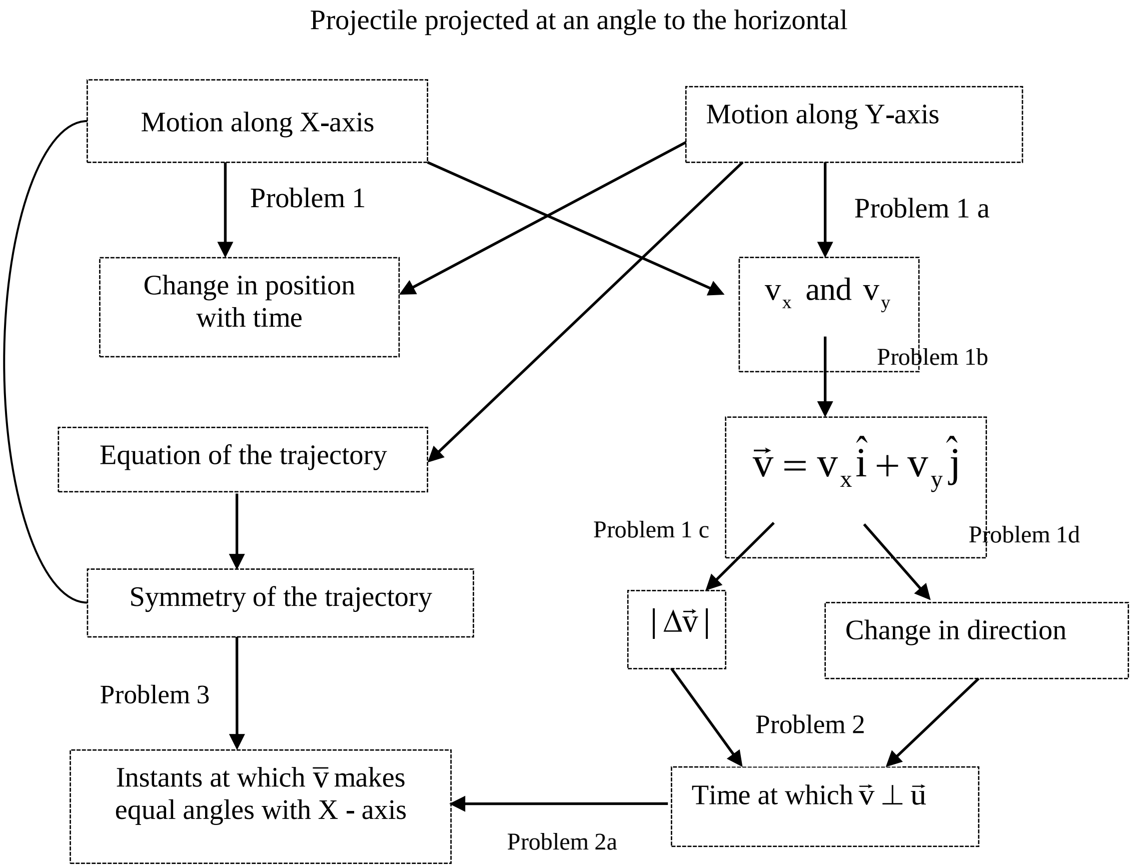


Figure 4: Conceptual grid diagram of Problem set -1

Samples from control group version of problems

1) A ball projected from the ground at 45° to the horizontal has an initial velocity of 20√2 m s^{-1}. What is the change in the position of the particle between t = 0 s to t = 3 s at successive time intervals of 1 second? What is the magnitude of change in velocity between t = 0 s to t = 3 s?

2) At a point on a parabolic path, the velocity of a particle is 100 m s^{-1} at an angle of 30° with the horizontal. After what time interval will the particle be moving at right angles to its former direction? (g = 10 m s^{-2})

3) At t = 0 s, a small ball is projected from the ground with an initial velocity of 60 m s^{-1} at 60° to the horizontal. What are the two instants of time when the velocity of the ball makes an angle of ± 45° with the horizontal?

Corresponding samples from experimental group version of problems

1) A ball projected from the ground at 45º to the horizontal has an initial velocity of $20\sqrt{2}$ m s^{-1}. The change in the position of the particle at successive time intervals of 1 s?

   a) What is the magnitude of velocity of the particle along X and Y axes at t = 1 s, t = 2 s, t = 3 s?

   b) What is the magnitude and direction of the resultant velocity at each of these instants?

   c) What is the magnitude of change in velocity between t = 0 s to t = 3 s?

   d) What is the change in the direction of resultant velocity between t = 0 s to t = 3 s?

2) At what instant of time will the direction of motion of the particle be at right angles to the original direction of projection?

   a) If a particle is projected at an angle α with a velocity u from the ground, after what time interval will its direction be perpendicular to the original direction of projection?

3) At what instants of time, t_1 and t_2, are the velocity components of the particle make an angle ± 45° with the X-axis?

Problem solving session 2

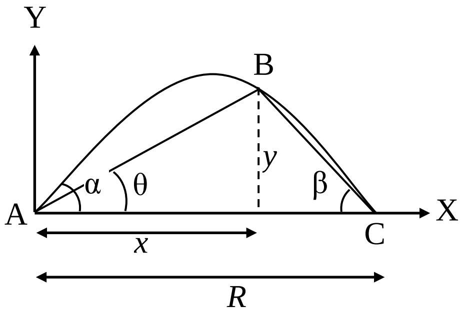
A similar exercise was repeated with a new set of situations on the same topic.

The following concepts were chosen:

- Angle made by the position vector with the X-axis and its relationship with the angle of projection
- Initial velocity required to cross a given barrier from a position on the X - axis.
- Time lapse between crossing two barriers of equal heights and its relationship with the initial velocity.

Samples from control group version of problems

1) A particle is thrown over a triangular frame ΔABC from A which is one end of the horizontal base AC. It goes grazing the vertex B and falls on the other end at C. If α and β are the base angles and θ be the angle of projection, then show that $\tan\theta = \tan\alpha + \tan\beta$

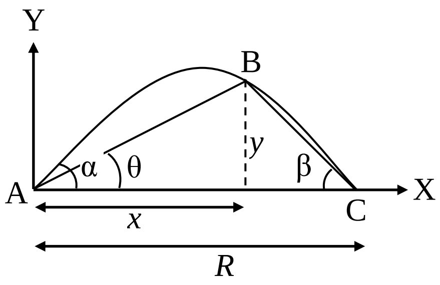


2) A ball is thrown from the ground to clear a wall 3 m high at a distance of 6 m and falls 18 m away from the wall. What is the angle of projection of the ball?

3) A particle is projected with a velocity $2\sqrt{gh}$ so that it just clears two walls of equal heights h which are at a distance of $2h$ from each other. What is the time required to pass between the walls?

Corresponding samples from experimental group version of problems

1) A particle is thrown over a triangular frame ABC from A which is one end of the horizontal base AC. It goes grazing the vertex B and falls on the other end at C. If α and β are the base angles and θ be the angle of projection, then show that $\tan\theta = \tan\alpha + \tan\beta$



a) What should be the angle of projection if x = y?

2) If in the previous problem another projectile be launched at the same angle θ from a point P along AC such that it grazes the point B, then what is the position of point P?

a) If both the particles are projected with the same velocity, which of them will cross the point B first?

b) How much time is elapsed between the two particles crossing point B?

c) What will be the position of one projectile while the other crosses the point B? How far are P and B?

3) What is the time required for a single projectile to pass between P and A?

The concepts were connected as follows:

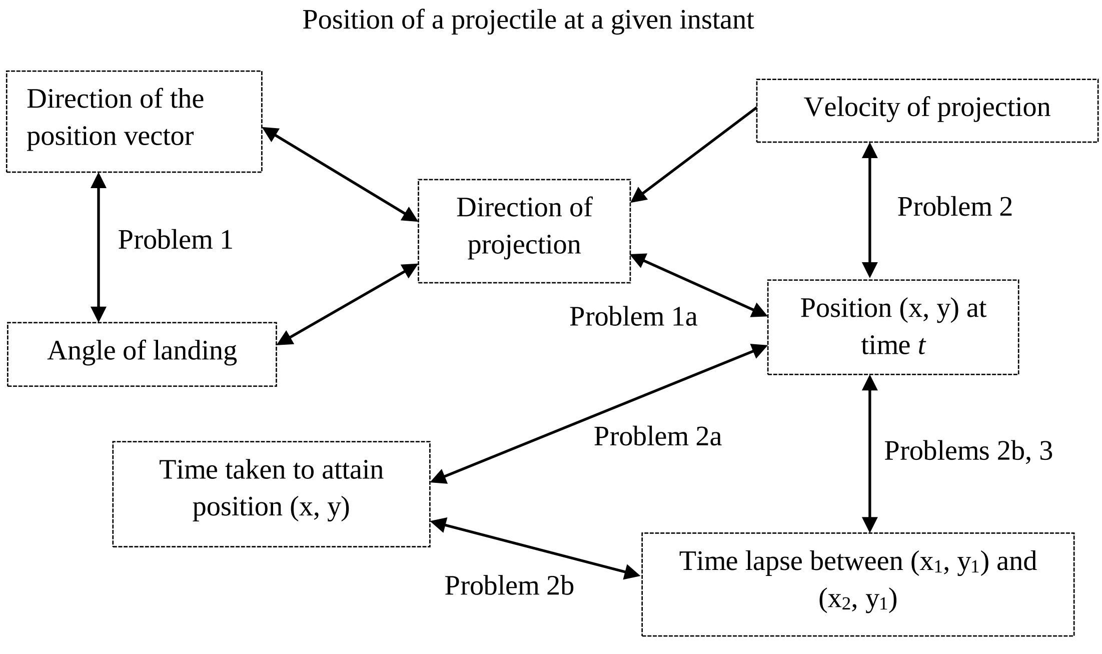


Figure 5: Conceptual grid diagram of Problem set -2

Assessment

The final test was common to both the groups and contained 15 problems of the end of the chapter variety, each carrying 2 marks. The problems were not in any way similar to those worked out in the class but were from the concepts covered in the lectures. Questions 1, 2 and 11 were on the same concept and could be connected. Questions 5 and 8 were connected. Questions 3, 6, 7 and 12 were connected. Questions 4, 13, 15 were connected. Question 14 could be solved by networking with either 6 or 13. The scores were awarded based on the conceptual understanding and correctness of the solution.

Observations

Most of the students in the control group chose to solve problems in the order given. Many in the experimental group attempted problems in an order of conceptual connections in the problem set. Performance of the experimental group was better than the performance of the control group;

a) the students of the experimental group showed better comprehension of the problems

b) two of the 15 problems which were relatively challenging were attempted by 5 students in the experimental group and by none in the control group.

c) 10 out of 17 students in the experimental group and 6 out of 19 students in the control group scored above 0.5 in the normalised scores

The following plots represent the final performance of the students in both the groups:

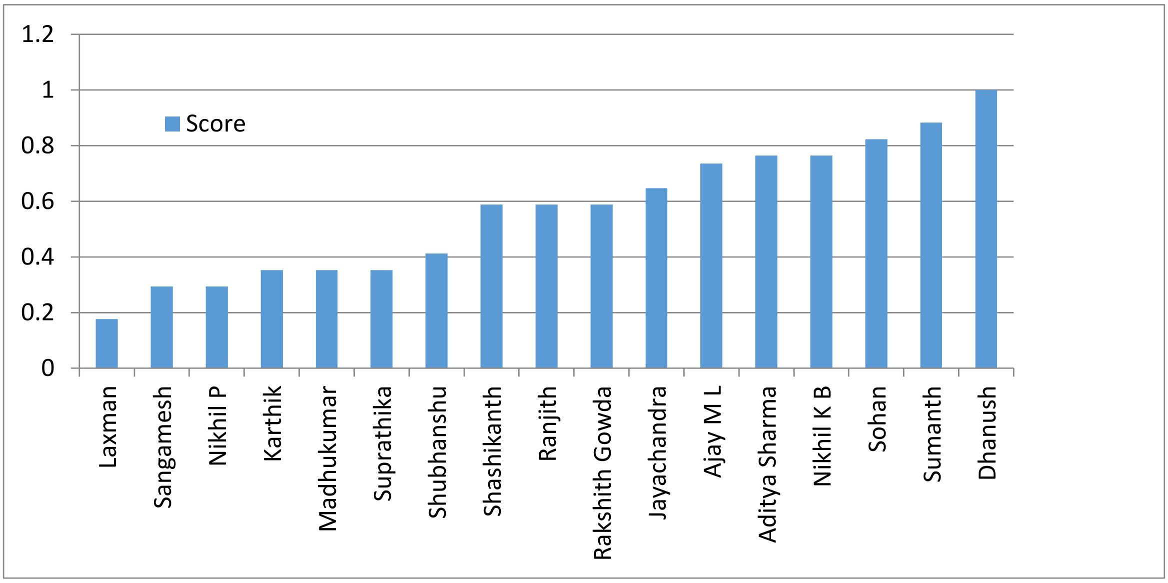


Table 3: Final performance of experimental group

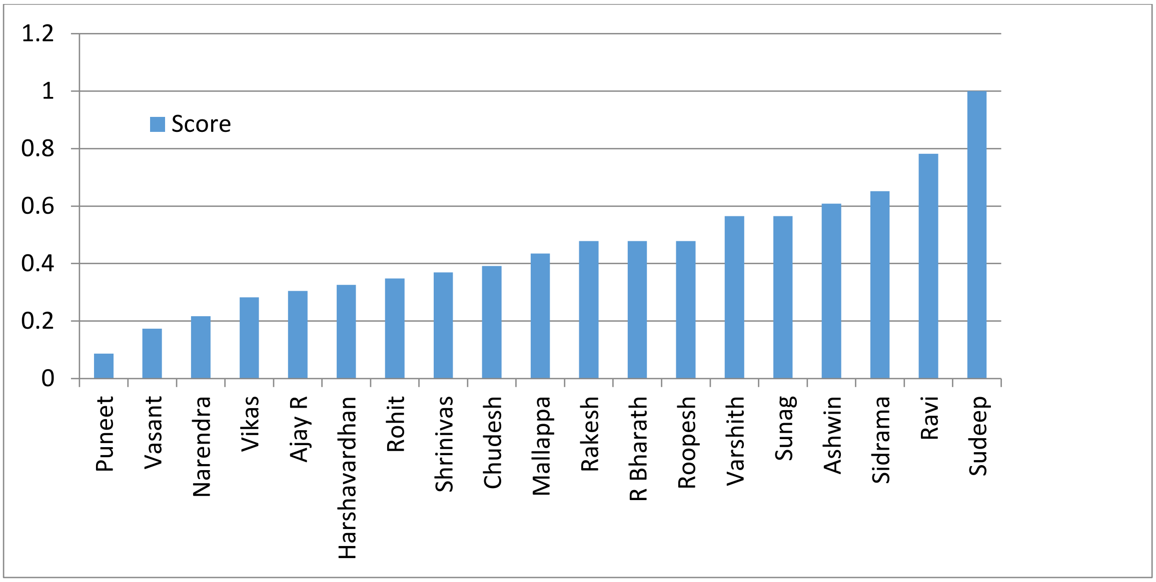


Table 3: Final performance of control group

Conclusion

The conceptual grid model was adopted for the study of Projectile Motion. The result of the final test indicates that the students trained on the Conceptual grid method of problem solving performed better. It is observed that 32% of the students in the control group scored above 0.5 whereas 59% of the students in the experimental group scored above 0.5 in the normalised scale. Based on the initial encouraging results, the conceptual grid method of instruction for effective acquisition of problem solving skills can be preferred. The method effectively reduces the number of practice problems to a minimum number of networked problems spanning the topic. Besides, the method helps a student understand the environment of a problem and on encountering a new situation the student is better equipped to find a path that connects the given situation to an already encountered one with ease. Similar work in other topics of physics to further validate the method is in progress.

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“THE SOIL IS ALIVE!” – EXPLORING EMERGENCE OF EMBODIED ENVIRONMENTAL SENSIBILITIES IN AN URBAN FARM

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The role of human actions in the destruction of the environment is now widely acknowledged. To contain this runaway destruction, actions that support the environment need to be promoted widely, particularly through the education system. However, the currently dominant approach of merely providing information about the state of the environment does not lead to environment-oriented actions. This understanding has led to a corporeal turn in the environmental education literature, to focus instead on 'action-competence'. These approaches argue for the primacy of sensory experiences in're-animating' the environment, thus fostering deeper connections that are unavailable through abstract conceptions of nature. To understand this approach to environmental education, we did a study based on an urban-farming project with 40 students, aged 12-13 years, for a period of 10 months. We took an analysis approach inspired by recent work highlighting the affective-aesthetic appeal of environmental entities, as well as embodied cognition models, examining students' interaction with environmental entities closely. Based on this data and analysis, we show how non-representational, meaningful encounters with nature, based on participation, contribute to the enhancement of students' environmental 'action-space'.

Introduction

The role of human actions in causing widespread environment destruction is widely acknowledged (MEA, 2005). Education is seen as an important measure to tackle this complex issue, specifically to nurture a culture that embraces environmentally-responsible actions (Armstrong, 2011; Barker, 2007; Huckle, 1999). Yet, dominant approaches to environment education (EE), based on providing information about the environmental issues, have been unsuccessful in seeding collective and impactful pro-environmental actions (De Young, 1996; Hungerford & Volk, 1990; Steg & Vlek, 2009).

Acknowledging the role of affect, context and socio-cultural factors in motivating actions, researchers have now shifted the emphasis to interventions based on practices, which encourage pro-environmental 'action-competence' (Barrett, 2006; Jensen, 2002; Jensen & Schnack, 1997). This pedagogical shift focuses on dynamic interactions with nature to develop ecological sensibilities, poses deep epistemological questions, particularly about the nature of knowledge where the environment is understood in terms of 'lived-relationships', rather than as a collection of objects awaiting scrutiny and control (Payne, 1999; 2016). The mechanisms underlying such interventions are also not understood, in terms of the processes motivating pro-environmental actions and the nurturing of broader sensitivity towards nature (Lugg, 2007).

In this paper, we argue that children's participation in practices embedding ecological principles helps develop an embodied sensibility towards the environment. Our intervention model is based on urban farming, which grounds children's involvement with complex ecological issues, and seeds students' further actions in the community. Based on our findings, we propose a possible model of the way motivations for community practices emerges from interaction with artefacts. We discuss the significance of this model in facilitating similar environmental interventions, and the educational implications of such embodied activities.

Framing EE as experience

The corporeal turn in EE is inspired by various schools of thought. Part of the work is based on critiques of EE approaches built on scientific positivism. This work questions the 'othering' of nature, where nature is presented as a resource to be acted upon (Bonnett, 2013). Apart from this critical approach, the virtue bestowed upon abstract rationality and its proxy concepts (such as trade offs, costs and optimizations), and the tacit acceptance of these as the key way to address environmental issues, has led to the search for alternate conceptions of EE. This work considers environmental issues as fundamentally ethical and moral dilemmas, which can be addressed only through appealing to values (Howell, 2013; Lockwood, 1999). This view leads to the question of “what is our relationship with nature?” The focus on an experiential conception of nature as the starting point for EE stems from this framing.

Arguments for 'grounding' of educative experiences also gather support from eco-phenomenological arguments which place subjective experiences as primary means of organising beliefs and knowledge about the environment. Tuning into one's sensory perceptions allows altering not just the content, but also the modality of perception (Heesoon Bai, 2015). A bodily experience of the world, Bonnett (2004) argues, allows engagement based on “responsive sensing” thereby involving “a deep appreciation of, and celebration of, the individuality of embodied things, an appreciation of the embodied by the embodied” (p. 99). The attentiveness to surroundings forms the basis for deeper relationships and a natural understanding of mutual co-existence.

Cognitive narratives of 'being in the world'

The argument for the primacy of experience in developing pro-environmental sensibilities is well supported by recent theories in cognition, which suggest that sensory motor interaction is central to shaping one's behaviour and thought processes (Glenberg, 2010; Glenberg, Witt, & Metcalfe, 2013; Hutchins, 1995). In particular, ecological psychology offers a rich platform for understanding individual participation in the environment as a dynamic interplay of actions and perceptions, thus making the body an integral component of cognition (Heft, 2015). Interaction with tools have been shown to change the body schema in real-time, to incorporate the tool into the representation of the body (Bernardi et al., 2013; Maravita & Iriki, 2004). This process is very fast, and extends the body's 'action space', suggesting that the body's relationship with the environment is highly plastic.

Recent studies extend this incorporation model to actions by others, suggesting that perceiving events enacted by others activate the same structures that direct one's own control of the actions (Knoblich & Flach, 2001; Sebanz, Knoblich, & Prinz, 2003), thus making others' actions part of one's action repertoire. Further, simulated actions, formally characterized as 'forward models', are now considered to predict events in the world. Increasing evidence suggests that such predictions form the basis for a sense of agency (Schubotz, 2007; Sebanz & Prinz, 2006). Feelings of empathy are also argued to arise from the capacity to resonate with others' actions and intentions (Decety & Ickes, 2011), and this process supports the formation of complex co-operative actions (Knoblich & Sebanz, 2008). As social animals, humans are naturally motivated to form strong interpersonal relationships (Baumeister & Leary, 1995), though this motivational process is not well understood.

Drawing on this wide literature, our study seeks to understand how embodied interactions gives rise to social initiatives, highlighting the role of artefacts such as plants, insects and compost in mediating collaborative actions at the community level.

Site of the study

To understand the above issues, we did a study based on an urban farming project, conducted with 40 students of grade VIII from a private CBSE school in Mumbai from June 2016 to March 2017. The terrace of the school served as the site for farming, and sessions were held for one and-a-half hours every week.

Research methodology

The study is exploratory, and based on an interpretative framework and qualitative techniques. Sessions on the farm were video-recorded, and students were asked to maintain their personal farm journals. The researcher maintained field notes along with a co-observer. Students usually worked in groups of 3-4. One student from each group was interviewed (total 14 interviews). The focus of the study was an exploration of students' evolving motivation towards farming, their relationship with different artefacts on the farm, and instances that provided the impetus for larger perspectives, or actions away from the farm site.

The project span covered 26 sessions. Grounded theory methodology was adopted to allow for data to inform the theory building process. This approach also allows focusing on linkages between conditions, actions and consequences (Corbin & Strauss, 1990; Eisenhardt, 1989). The interviews were repeatedly read by the researcher, followed by highlighting relevant quotes using different tags. These tags were refined to generate the first draft of the codes. A refined list of codes and definitions was generated through discussions.

Description of the project

The project was deliberately kept open-ended with broad goals of growing plants using principles of organic farming, while using minimal resources. The project was not a graded activity. Setting up the farm included making a compost pit, collecting dried leaves to add to the compost and mulch the plants, making sapling planters, making cardboard planters, making supports for climbers and creepers, plant care, saving seeds and harvesting. Occasionally, a liquid called *Amrit Jal* made from a mixture of water, cow urine, cow dung and organic black jaggery was added to the plants to help in microbial growth of the soil.

Most students in the school had grown up in cities, and had fairly limited ideas about growing plants. Students were allowed to explore, observe and play while participating in various activities.

Emerging themes

Somaesthetic interactions

Students were observed to engage with plants in a rich, visceral manner, through senses of touch, smell and taste, thus widening their modalities of perceiving the environment. As Bai (2013) argues, instead of appealing to vision-based discursive categorisation of the surroundings, a more sensuous perception arouses a participatory consciousness, and nurtures an emotional relationship. To illustrate, students had never seen the plant called Indian Roselle (locally called Ambadi). It was grown on the terrace, and they were informed that the leaves of the plant are edible. Initially, for most students, the mere idea of eating something directly off a plant was a novel concept, given that their interaction with food is mostly in packaged, frozen or cooked form. However, apprehensions gave way to curiosity, as they began to sniff, taste and finally nibble the leaves tentatively. The sour-tasting leaves went on to become a garden favourite, and in the process encouraged them to taste other plants too. Students began identifying plants based on sensory interactions such as "waxy leaves", "thick leaves", "minty taste", "sour taste", "sharp leaves" and so on. Using the body as an "organising core of experience" Shusterman (2004, p. 51) accentuates the immediacy of experience, along with a growing sensitivity to anticipated changes in the surroundings.

Many students were initially repulsed with the organic matter kept for composting, but began shedding their inhibitions after seeing their saplings grow in the compost. In subsequent sessions, they noticed that the compost once prepared, had a sweet smell. Then, they began taking active interest in compost preparation, and would often smell it, feel its texture, and poke around to look for earthworms, the presence of which would generate a lot of excitement. Given, that they had started out with a bare space, the emerging life-forms and relationships initiated more actions to encourage further growth. Such engrossed participation prompted a student to remark,

"*we never even touched plants this way earlier… I mean we play on the grass, but not this way. To take care. This time we learnt how to grow the plant, otherwise it is said that just drop a seed and the plant will grow... the book says that. But now I think the book is very fake, because the book only says what the author can see, but while doing it we see many different things."*

Bonnett (2010) argues that formal schooling institutions act as places of 'unselving', since the focus on imparting abstract information is not as effective as the engagement, responsiveness and sensitivity that arises from authentic experiences that constitute a sense of identity.

Instances of enchantment

Pyyry (2017) describes *enchantment* as participation in encounters with the environment that offer a simultaneous moment of immersion and disconnect from the world. It could be conceived of as a precursor to a reflective engagement, and pave way for a deeper relationship. Jane Bennet (2009) argues that enchantment is crucial to ethical being-in-the-world. Students found themselves continually amazed with revelations that turned the mundane into extra-ordinary and everyday encounters into novel perceptions. To illustrate, seeds germinating from the compost pile made for a moment of awe as students gingerly picked it up from the pile, closely observing the fragile roots and a single leaf on the verge of emerging from the cotyledon. Another phenomenon that captivated their attention was the fruiting of flowers, with swollen ovaries and dried petals. Despite 'knowing' the process through textbooks, the actual observation turned out to be a novel experience for them.

Seeds became another fascinating entity, as many realized for the first time that the fruit had to be left to ripen and finally dry on the plant to save its seeds for the next season. They split open a dried Okra pod and found that the seeds have a fine hairy covering over them. Okra is a fairly common vegetable and all students had seen them being cooked at home, but seeing it grow on the plant, and eventually yield seeds made them look at the vegetable in a different way. Many took seeds back home to grow their own plants. The fleshy, purple seeds of Malabar spinach, also used as a natural dye, attracted the students with its deep hue. The miniscule size of Amaranth seeds was another phenomenon for them to explore, as evident in a student exclaiming,

“One seed can grow one plant and we get so many seeds from it! Hundreds of them...”

The sheer number of seeds from each plant constituted moments of amazement and subsequent spaces for reflection. Students came to treat seeds with a lot of care, and ensured that seeds were collected carefully, often spending the entire session just storing them in packets for future use.

The variety of creatures seen on the farm, as the number and size of plants grew, constituted another dimension of experience, as most students were initially very scared, but fascinated, with the mysterious ways in which creatures appeared in the soil, or on the plants. In fact, many students had spontaneous “bug rescue missions” wherein they looked around for worms crawling on the terrace, and put them back in the soil to save them from getting trampled accidentally. Even snails, usually considered a pest in gardens won their affection, as one of the students actively defended it by saying,

“*We can give it some fresh leaves to eat too. We don't need to harvest everything!*”

Numerous such instances signify their active participation and growing concern for the well-being of the plants, which went on to encompass other living beings on the farm. Much of this 'care component' had its roots in instances described above. These observations echo with Martin's (2007, p. 62) arguments,

“Caring demands that a sense of proximity be created by having students engaged in experiencing, learning and sharing time with nature in the same sorts of ways we might get to know a new friend.”

Motivational triggers

Novelty

The idea of accessing new entities, or different ways of using them, encouraged many students to pursue activities on the farm with more interest. Most of them recounted that different facets of the farm (ranging from plants to supporting artifacts like plastic bottles and trellis) kindled their enthusiasm to explore related tasks. To illustrate, a student had transplanted a sapling of dwarf morning glory, which later grew and flowered, attracting many bees on the farm. The student was extremely happy seeing the plant blossom, and said,

"*I spoke a lot about my plant to my mother because it was something I had never really seen before. It was new to me.*"

Similarly, another student recounted,

"Like 'bhindi' ko first it should be dried and then the seeds should be taken, then I never knew ambadi, I learnt that. Then many new plants also like Malabar spinach and all I didn't know, then pumpkin flowers also. I had seen those plants, but I didn't know it was pumpkin."

Many more events on the farm turned out to be a new experience for the students, and built the motivation to search for something new, as an artifact, skill or sensory experience.

Challenge

Students found some tasks challenging, such as figuring out how to provide support for climbers by tying up bamboo poles, and reinforcing cardboard planters so that they could survive the monsoon. However, the challenge motivated them to work out solutions that could be applied in the given context. They made tripod designs and worked in collaboration to make structures that could be used on the farm. They reported the process to be quite enjoyable, perhaps because it involved peer validation and had a tangible outcome of having a stable support for the plants. As a student commented,

"*then most important was that trellis. Making it was a fun job because we were trying different knots that we knew but had never really used. So, it was a very enjoyable."*

Autonomy

Students enjoyed the open atmosphere of the activities, since they could decide how they wanted to set-up the farm, with minimal guidance provided, only when required. The freedom also resulted in them assuming responsibility for the upkeep of the farm, and they often stayed back even after the session was over, or volunteered to come during holidays to ensure that the plants were taken care of. One of the students spoke about the experience by contrasting it with other outdoor activities done at school,

"*this gives us a lot of liberty and freedom to do what we want to, because now, choosing the seed we want, harvesting many plants. In school you have a large number of children, so work has to be divided equally to everybody. Then because there are many children, you don't get a lot of work, you just do something small, then you sit down. Here, there is so much going on continuously that, if one thing is over then you can go into the other and help them out. So it is really nice.*"

Louise Chawla (2002) notes that environmental affordances that promote responsible relationships, and opportunities to take responsible roles in community settings, are integral to nurturing children's agency in the society. In a similar vein, (Hart, 2000) describes the importance of authentic participatory experiences, which allow students to understand the gravity and relevance of their actions, in contrast to school activities that work as mere symbolic actions.

Feedback

The evolving landscape of the terrace farm became an interesting form of feedback for the students, who started noticing different aspects of plant growth, as evident in a remark made by a student:

"*we studied that the tendrils wrap around the support, but now I actually saw how it wraps itself... we hadn't learnt about grouping plants like this... this is new, we haven't studied like this... I saw the good effects also... Like that ajwain plant needed some shade... under full sun it didn't have so many leaves... now under a bit of shade it has grown a lot..*."

Many students could see the direct impact of their actions on the plants and their surroundings, thus prompting them to take more interest in related activities. Further, these activities became an interesting topic for discussion at home, or with other teachers in the school, wherein students felt a sense of accomplishment and joy in sharing their observations and learning. The positive feedback received from parents and other individuals encouraged students to continue sharing their experiences at the farm. As one student commented,

"like on one of the Saturday we had science period, and we told the teacher what we are doing on the terrace... also we were very enthusiastic to tell our granny (lady employed in the school canteen) *what we are growing, we have discussed it with everyone... They are very happy"*

Sustained engagement seemed to have been an important dimension in ensuring that students received continuous feedback regarding their efforts through the artifacts themselves, or through people around. Such sharing of impressions and activities seems to have provided the impetus to widen the scope of their activities. This is discussed in the next section.

Actions away from the farm site

Students reported diverse ways in which their immediate community became involved in different activities related to the farm. In particular, senior citizens, who have prior experience of growing plants, helped students in various activities. Such instances also helped in community building, as students' expanding 'action space' could be shared among other disparate individuals (such as older people) having similar interest, and this overlap motivated them to explore more activities in this space. For instance, a student remarked,

"Earlier when my grandmother used to mention it (gardening)*, it wasn't a topic of much interest to me because I did not know anything about it. So I used to just avoid this topic. But now that I have seen so much happening and it is so exciting, so I have started to help my grandmother out. In fact, when I told her about all this* (terrace farming)*, then she got hyped means totally hyped. On the same day, she did not tell me, she went to the nursery, bought a few saplings, seeds, pots, mud everything and she brought it home. Now, we are growing a lot of stuff."*

In other cases, parents helped students compost at home, or save cardboards, bottles and other materials that could be used on the farm, instead of disposing them. Some students also secured small spaces around the residential societies to start a community garden, and found support from individuals who were already interested in such activities.

Broader environmental sensibilities

The various activities on the farm gradually reflected in more general thoughts pertaining to the environment, many of them taking shape through direct engagements or discussions on the farm.

For instance, plastic bottles are synonymous with trash, thrown away soon after being bought. On the farm, however, discarded plastic bottles were cut and used as sapling containers, thus turning a common waste entity into a low-cost resource. Many students began to look for other materials which could be used as planters. On the other hand, sorting plastic from the compost led to many discussions regarding the amount found in the environment, and they began questioning its use in packaging, along with alternatives. Usage of dried leaves on the farm sensitized students about the usage of dried biomass in their vicinity, and they made efforts to collect the biomass, and in some instances stopped locals from burning it.

Their engagement with composting, adding cow-dung slurry and mulch to soil helped them appreciate the richness of soil as an entity. For example, a student remarked,

"Earlier we thought soil is just something we get in packets and plants will directly grow in it. But now, we are realizing that it needs cow-dung, dry leaves, and many decomposition materials that improve the nutrients. This has really changed what I thought about soil."

Another outcome included the social bonding experienced by students as different situations required them to work as a group, and collaboration made more sense than just tending to a single plant that each one might have grown. As a student commented,

"here you get to spend plenty of time with plants as well as other people. You share experiences that people know and you listen and share your experiences as well... You get to work with people who you don't really interact with as well..."

Discussion

This case study provides insights into how aspects of a pro-environmental community practice mediated changes in students' action capacities and perspectives. In particular, it describes the significance of somaesthetic interactions in building students' interest and growing their sensitivity towards the farm. Affective episodes, termed as instances of *enchantment*, serve as precursors to active participation and care of the plants and other living beings. The freedom of exploration and interaction with various entities on the farm provided different motivations to surface, ranging from novelty, challenge, autonomy and feedback.

The expansion of the farm experience to activities in spaces away from the farm site is a significant aspect of the study, especially since most of these activities were done in groups. We postulate that activities where joint-action is a central component have the ability to generate motivation, particularly to engage with and expand the possibilities of work, because social experiences are rewarding by themselves. As Marion Godman (2013) argues, social motivations seem to form a distinct factor contributing to joint-actions, apart from shared intentions and representations. The increasing involvement of teachers and parents as volunteers on the farm, through the students' sharing of their experiences, suggest an important role of social motivation in facilitating community participation. The following diagram elucidates a proposed model of motivation seeding joint-action.

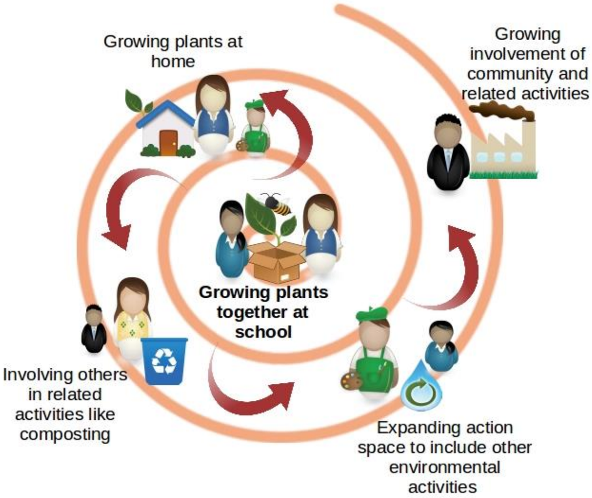

Figure 1: A proposed spiral model of motivation, where sustained engagement with the core activity motivates participants to involve and expand their action space. In this case, growing plants on the school terrace led to concern in related aspects such as composting, seed-saving etc, and also facilitated growing participation of other individuals.

Sustained engagements at the farm contribute to new perspectives generated by 'performative' and 'coagulative' substances such as the soil, planters, compost and so on. These are performative substances because working with them allow students to grasp the embedded values such as interdependency, dignity of labour, avoiding food wastage etc. in an enactive and embodied (i.e. non-descriptive) way.

There is a need for designing similar practices that embed such 'performative-substances', which help coagulate various environmental themes into values, thus providing engagements that lead to the development of resilient environment-oriented communities. Such building of integrative world-views, through sustained interactions with artefacts and community, can form the basis for a perspective we term as 'Solving for Pattern'. Originally coined by Wendell Berry (1981), 'Solving for Pattern' constitutes a relational ontology, which supports the understanding of ecological principles, particularly interdependent relationships. An experiential approach to environment education may be critical to embracing such animistic ways of being, where dynamic relations with the immediate environment become central to one's identity, agency and well-being.

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VECTORS IN HIGHER SECONDARY SCHOOL TEXTBOOKS

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Vectors are introduced in higher secondary grades in mathematics along with their applications in physics. Anecdotal evidence suggests many students struggle to grasp the concept of vectors and its applications. However, in the Indian context, there has never been a systematic effort to understand the cause of this difficulty. In this paper, we contend that the paper-based medium of textbooks presenting these topics is one of the main causes of the difficulty citing certain limitations, we found in them. We report an analysis of presentation of the topics related (including prerequisites and applications) to vectors in physics and mathematics textbooks for grades 8-12 of two Indian curricula (NCERT, Maharashtra State board). The failure to link geometric and algebraic modes of adding vectors, inadequate scaffolding for understanding resolution are identified as some key limitations.

Vectors and the difficulties

Like many topics in mathematics and physics introduced in the higher secondary school curricula, vectors also turn out to be abstract and with a wide range of applications across topics in physics like mechanics and electromagnetic theory. Vectors form a mathematical language to formalise the understanding of various physical phenomena and concepts ranging from velocity and force in mechanics to magnetic and electric forces and fields. This importance of vectors was acknowledged for the role they play in the ability of students handling physics concepts, especially in Newtonian mechanics (Roche, 1997; White, 1983). This application in physics often turns out to be a nightmare for students due to a variety of reasons. Physics education research acknowledges the inability in reasoning with vectors to be one of the key hurdles in handling forces, which are vectors (Knight, 1995). Thus, the understanding of vectors and vector operations is crucial in certain cases of physics at earlier stages (higher secondary or pre-college level). Besides its diverse applicability, vectors, as a mathematical topic, require a wide range of prerequisites to be able to understand and work with them correctly. For example, trigonometric connection is central to the vector operations like resolution. Understanding of trigonometric ratios as ratios of sides of a right-angled triangle and its connection to the unit circle and horizontal and vertical coordinates or distances (called trigonometric connection) are found to be fragmented among students (Brown, 2006). Various studies (Byers, 2010; Gur, 2009; Jackson, 1910; Orhun, 2004) hint at trigonometry as a very difficult topic for both teaching and learning in the transition in high school curricula. Also, the basics of the geometry of lines and angles and of triangles would be essential for understanding various operations on the vectors. Other problematic issues include the differences in the way vectors are dealt with in mathematics and physics (Dray & Manogue, 1999), the jump from understanding and operating a scalar (where normal algebra holds) to a vector (a mathematical entity with new operations) (White, 1983). Also, students' preconceptions and intuitive knowledge about certain physical quantities are in conflict with notions of vectors as studied in detail using vector knowledge test (Aguirre & Erickson, 1984; Aguirre, 1988; Aguirre & Rankin, 1989).

Various studies in the past looked at the problems students face in understanding vectors (Aguirre & Erickson, 1984; Knight, 1995; Nguyen & Meltzer, 2003), and propose multiple instructional and pedagogical strategies to handle these topics (Hake, 1998). But not many studies look into the textbooks as one of the primary sources of difficulty in learning vectors, except for a few which handle this issue at the level of conceptual inconsistencies of the statements (Bauman, 1992). Textbooks usually set up all the teaching and learning practices in the classrooms. The scope of the topics, the flow and often even the narrative used in the classroom is tightly tied to the textbooks. We, taking a broader and different lens, contend that the way the content is presented and covered in the textbooks is one of the main reasons for the difficulty that the students tend to face. We present an analysis of curricula in India, covering the topics related to vectors. We capture the presence or absence of links and scaffolds between topics that are provided in the textbooks and also point at the possibilities of difficulties that could arise leading to a weak understanding among the students. We chose the textbooks of NCERT curriculum, one of the popular and well-researched curricula in India, and a curriculum followed in Maharashtra (an Indian state) State Board, as two cases for our analysis. Using the analysis, we identify certain limitations and report some evidence from other popular physics textbooks. Eventually, we explore the possibility of these limitations in the textbook stemming from the paper-based medium used to represent content, which is dominantly static in nature.

The analysis

In this analysis of curricular presentation of vectors, we focused on the transition from the high school into the college or university levels, the stage where the students would have covered various pre-requisites, would be introduced to vectors and are expected to apply them extensively in physics. In India, these topics of interest span in the textbooks of mathematics and physics (science, in lower grades) from around grade 8-12. We looked specifically at how the topics covered in different textbooks at different grade levels are interlinked and point out places where there are gaps for students, which actually need to be scaffolded for a holistic understanding. The vector related topics at this level include the definition of a vector, and denoting and handling them geometrically and algebraically, operations of addition and resolution, and certain application in mechanics. We also analysed the coverage of the prerequisites like the geometry of lines, angles and triangles, trigonometry (usually covered in the lower grade level mathematics textbooks). We identified and categorised these vector-concepts, its applications and the needed prerequisite-concepts into 23 topics (concepts, procedures) which form our units of analysis (referred to as just units from here onwards). They are: properties of angles and lines, trigonometric ratios, applications of trigonometric ratios in the cases of heights and distances, unit circle, direction of a vector (vector definition), magnitude of a vector (vector definition), triangle law of vector addition, polygon law of vector addition, parallelogram law of vector addition, rectangular components (resolution) of a vector, unit vectors, non-rectangular components (connection to resolution), algebraic addition (using rectangular components), rotation of frame of reference, resolved forces, resultant forces, application in the cases of inclined plane, 3D components, polar coordinates, geometric interpretation of scalar product, algebraic procedure of scalar product, geometric interpretation of vector product, and algebraic procedure of vector product.

Capturing the way these units are presented in the textbooks to assist students' understanding, we analysed for inter-linkages between these units. The 23 units (listed above) earlier are related to each other and these interlinks are important for the student to understand the entire conceptual space of vectors. In the ensuing 23 x 23 link map (or a matrix), only certain links are relevant (like the trigonometric ratios and the rectangular components of vectors). But certain links may not be relevant (e.g. trigonometric ratios and the definition of vector and triangle law of addition of vector). This link matrix was developed by us, and may not be unique. However, we assume that the nature of the matrix is such that any similar matrix developed would broadly remain same and the differences if any would be very minor. Each of the relevant unit links was coded using a coding system capturing an elaborate set of details for both the curricula (textbooks from grade 8-12). Each code had 8 characters (ABCDEFGH) capturing the grade, textbook and the chapter, then the mode of dealing with the link (explanations or example problems) and the rigour with which it was presented on a scale of 5 (0-4) standing for not present (not stated), weak (incorrectly or inadequately stated), moderate (correctly or adequately stated), weak evidence (stated correctly with inadequate evidence/ proof), good evidence (stated correctly with adequate evidence/ proof provided) respectively. Each of the relevant unit links was coded using the coding system described above for both the curricula (textbooks from grade 8-12). Given this set of items that we are interested in, we undertook two kinds of analysis (link analysis and flow analysis).

1. Link analysis

Here, we captured the presence or absence of the essential links in the curricula. We analysed for the mode of presentation (whether explained in the content or using example problems). This helped us look for the possible reasons for the absence of certain units with different levels of rigour or certain modes of presentation for certain units, which gives us a sense of the feasibility of the textbook as a medium to handle a particular link in either of the modes, and hence about the limitations of the medium. The rigour of presentation gives a sense of the topics where extra efforts or scaffolds are needed to make the students understand the concepts involved.

Rigour of links:

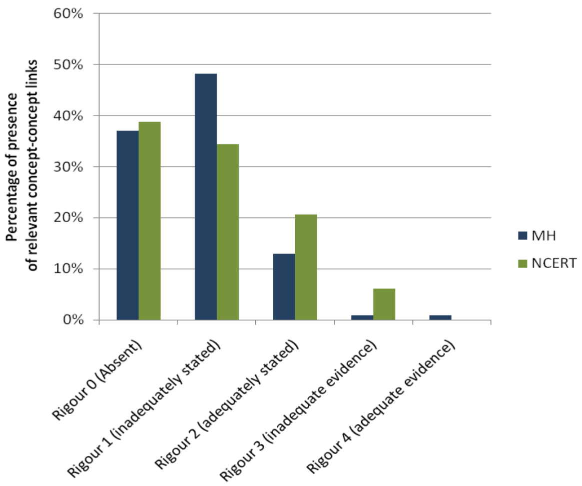

Figure 1: Presence of various unit links across rigour levels (NCERT and MH).

Here, we looked for the rigour of presentation of various unit links in both the curricula. About 40% of the relevant the interconnections between units are not presented (rigour 0- see figure 1) in both the curricula. MH curriculum presents a bit more (48%) unit links with less rigour [rigour 1 (stated weakly)] as compared with NCERT (34%). NCERT presents close to 13% more links than MH with better rigour (rigour level 3 and 4). Though lack of inter-linkages between specific topics is not visible in the chart, a general distribution of the links across rigour levels can be noted. This clearly shows a majority of essential links either absent or weakly presented. Looking at certain specific units with a less rigorous presentation, let's see some examples. The topics of trigonometric ratios are introduced in the lower grade mathematics curriculum. The notion of a unit circle is also briefly introduced in the case of trigonometric functions. And these are immediately used in cases like the resolution of vectors. Trigonometry itself is a topic which is considered difficult among the students and an application of it in the new context of the resolution of vectors could be even more intimidating to the students. A more rigorous and detailed way of dealing with the hows and whys of using the trigonometric ratios in the process of resolution to rectangular components using the right triangle was missing. Similarly, the processes of addition done using geometrical method (triangle or parallelogram laws) and using algebraic method (using the rectangular components) are not well connected. A process description of how the addition of rectangular components and the addition using geometric addition are equivalent was not dealt with. This connection is essential for the students to imagine and understand the spatial significance of the algebraic manipulations they perform using the rectangular components. A similar trend of lack of scaffolds for applications in physics could be found in other topics such as integral and differential calculus at this stage of schooling.

Modes of presentation - explanations and examples:

It is always interesting to note the mode of presentation of a particular unit or link between two units. The two characters F and G, capturing on the presentation in explanations and the example problems respectively, could reveal certain interesting patterns.

The first two characters show 1,0,-1 comparing the NCERT and MH texts. The last character gives the (NCERT-MH) (difference of rigour between NCERT and MH text books)	ABCDEFGH	Direction (Vector Definition)	Magnitude (Vector definition)	Rectangular Components (Resolution)	Non-rectangular Components (Resolution)	Unit Vectors	Triangle Law	Polygon Law	Parallelogram law	Rotation of Frame of Reference	Resolved Forces	Resultant Forces	Inclined Plane	Properties of Angles and lines	Trigonometric Ratios	Unit Circle	Heights and Distances	3D components	Polar Coordinates	Geometric Interpretation of Scalar Product	Algebraic Interpretation of Scalar Product	Geometric Interpretation of vector Product	Algebraic Interpretation of vector Product	Algebraic addition(using rect comps)
Direction (Vector Definition)	11	00	-	11	10	10	11	01	11	01	00	11	-	-	-	00	-	10	-	10	10	11	00	10
Magnitude (Vector definition)	11	-	00	10	10	10	00	00	11	01	00	11	-	-	-	00	-	10	-	-	-	10	11	10
Rectangular Components (Resolution)	11	11	10	00	10	11	-	-	10	10	00	10	10	-	00	00	-	11	01	11	11	11	11	11
Non-rectangular Components (Resolution)	11	10	10	10	00	00	00	00	00	-	-	00	00	-	-	-	-	-	-	-	-	-	-	00
Unit Vectors	10	10	10	11	00	00	-	-	-	00	00	00	-	-	-	00	-	11	01	-	11	11	11	11
Triangle Law	11	11	00	-	00	-	00	01	11	-	-	11	-	-	-	00	-	-	-	-	-	-	-	00
Polygon Law	01	01	00	-	00	-	01	00	00	-	-	00	-	-	-	-	-	-	-	-	-	-	-	00
Parallelogram law	11	11	11	10	00	-	11	00	00	-	-	01	-	11	00	00	-	00	-	-	-	-	-	11
Rotation of Frame of Reference	01	01	01	10	-	00	-	-	-	00	00	00	00	00	-	00	-	00	00	-	-	-	-	-
Resolved Forces	10	00	00	00	-	00	-	-	-	00	00	00	00	-	00	00	-	-	-	-	-	-	-	00
Resultant Forces	10	11	11	10	00	00	11	00	01	00	00	00	00	-	00	00	-	-	-	-	-	-	-	00
Inclined Plane	10	-	-	10	00	-	-	-	-	00	00	00	00	00	-	-	-	-	-	-	-	-	-	-
Properties of Angles and lines	11	-	-	-	-	-	-	-	11	00	-	-	00	00	-	-	01	-	10	-	-	-	-	-
Trigonometric Ratios	11	-	-	00	-	-	-	-	00	-	00	00	-	-	00	11	11	01	11	11	-	11	-	11
Unit Circle	11	00	00	00	-	00	00	-	00	00	00	00	-	-	11	00	-	00	11	-	-	-	-	00
Heights and Distances	11	-	-	-	-	-	-	-	-	-	-	-	-	01	11	-	00	-	-	-	-	-	-	-
3D components	11	10	10	11	-	11	-	-	00	00	-	-	-	-	01	00	-	00	01	-	11	-	11	11
Polar Coordinates	11	-	-	01	-	01	-	-	-	00	-	-	-	10	11	11	-	01	00	11	00	01	-	00
Geometric Interpretation of Scalar Product	11	10	-	11	-	-	-	-	-	-	-	-	-	-	11	-	-	-	11	00	01	-	-	-
Algebraic Interpretation of Scalar Product	11	10	-	11	-	11	-	-	-	-	-	-	-	-	-	-	-	11	00	01	00	-	-	-
Geometric Interpretation of vector Product	11	11	10	11	-	11	-	-	-	-	-	-	-	-	11	-	-	-	01	-	-	00	01	-
Algebraic Interpretation of vector Product	11	00	11	11	-	11	-	-	-	-	-	-	-	-	-	-	-	11	-	-	-	01	00	-
Algebraic addition(using rect comps)	10	10	10	11	00	11	00	00	11	-	00	00	-	-	11	00	-	11	00	-	-	-	-	00

Figure 2: Explanations (F) provided for various unit links, xy in each cell $F_{NCERT}F_{MH}$.

Cell Legend: Green 11- explained in both NCERT & MH; Red 00- not explained in both NCERT & MH; Yellow 10 - explained only in NCERT; Blue 01 - explained only in MH

See figure 2 for the analysis of explanations. Both the curricula present a wide range of links in the explanatory sections. NCERT appears to focus more on using explanations strengthening links between the fundamental units like the definition of the vector and the addition and the resolution, whereas MH board attempts to touch upon even the advanced concepts (as if it is just for the sake of covering) [yellow cells]. However, there seems to be a large number of units which are not explained in both the curricula. A significant chunk of them relate to the links between the components (non-rectangular) and addition (triangle, parallelogram laws) [the red cluster in the top left corner of the matrix]; those related to the application of the addition of vectors in the motion in plane (resolving forces, finding resultant forces, rotating a frame of reference) [red cluster in the centre of the matrix] and the connections with the unit circle. We had a chart similar to figure 2 for the case of example problems. Both the curricula present a lot of content using example problems. However, there are certain units which are not dealt with using the problems. The topics related to the non-rectangular components and the connection to the addition (using triangle or parallelogram law or the algebraic addition) is again not dealt with using the example problems. Interestingly the units, related to the application of resolution and addition of vectors in mechanics (laws of motion in a plane), are dealt with using the example problems. Although the statements of laws of motion are dealt with in the explanatory sections discussing the theories, the applications using the vectors are actually presented in the process of solving the example or exercise problems. Similar to the case with explanations, the topic of the unit circle is not dealt with in the mode of example problems. Further, the algebraic way of adding vectors is not linked with the geometric ways (triangle or parallelogram law) in the mode of example problems. NCERT appears to emphasize on linking the units with fundamental ones.

2. Flow analysis

Grade	9		10		11										12							
						Ph Ch 3									Mt Ch 10							
Subject/ Chapter	Math	Phys	Math	Phys	Math	Sq 1	Sq 2	Sq 3	Sq 4	Sq 5	Sq 6	Ph C5	Ph C6	Ph C7	Sq 1	Sq 2	Sq 3	Sq 4	Sq 5	Sq 6	Sq 7	Phys
Properties of Angles and lines	2																					
Trigonometric Ratios			3																			
Heights and Distances			3																			
Unit Circle					2																	
Direction (Vector Definition)						3									1							
Magnitude (Vector definition)						3									2							
Triangle Law							3									2						
Polygon Law							0															
Parallelogram law								3									2					
Rectangular Components (Resolution)										3								3				
Unit Vectors								2									2					
Non-rectangular Components (Resolution)									1													
Algebraic addition(using rect comps)											2											
Rotation of Frame of Reference												2						2				
Resolved Forces												2										
Resultant Forces												3										
Inclined Plane												2										
3D components															1							
Polar Coordinates					1																	
Geometric Interpretation of Scalar Product													2									
Algebraic Interpretation of Scalar Product													2						3			
Geometric Interpretation of vector Product														2						2		
Algebraic Interpretation of vector Product														2							3	
Applications of Scalar Product													2								1	
Application of Vector Product														2							2	2

Figure 3: Trajectory in NCERT Board (a similar chart made for MH Board as well)

The flow analysis is an innovative way of qualifying a curriculum's alignment with the actual learning needs and learning trajectory of the students. We could not find a similar analysis performed in the literature. This captures at a broader level the order in which the topics progress and the spread across textbooks in each of the curricula. This can also be used as a measure, at a logistical level, of the spread that the curricula have, and hence the level of difficulty that students and perhaps teachers could perceive in integrating them. We reorganised the 23 units along with the applications of scalar and vector products (for completion), into an order which we think would be a meaningful way of presenting them. A confirmation to our trajectory reflects in the chart (figure 3 for NCERT) as a straight unbroken diagonal from top left to right bottom. In NCERT (figure 3), the necessary concepts are covered across grades and textbooks. Here the basics mathematical concepts were covered in math textbooks of grade 9 and 10. Though the vector fundamentally is a mathematical topic, it is introduced and applied first in physics (grade 11) and then in mathematics (grade 12). Within physics, the concepts follow roughly out trajectory as shown by less deviation from the straight line. A similar chart made for MH board shows that the initial concepts like the angles in parallel lines till trigonometric ratios are dealt with in mathematics in lower grades of 8, 9 and 10. Vectors are introduced in grade 11 Physics Chapter 2 onwards and are applied in various later chapters, in which we see a break/deviation from our trajectory. As with NCERT, these are dealt with the math textbook only later in chapter 8. This analysis gives a picture of how widespread the necessary concepts in the curricula are and also the deviations hint at potential unpreparedness among the students. These hint at the difficulty that students might face in integrating these concepts without any support.

Findings & Limitations

From the analysis of topic links presented with varied levels of rigour, the mode of presentation (explanatory section or example problem), and the flow of units, captured by the above analysis, we could see certain patterns. Here, we shall elaborate on these patterns, look at certain other standard textbooks for a broader picture and argue for the limitations of the paper-based medium of the textbooks.

A linear and modular presentation

The fact that the units related to the vectors ranging from the geometry of lines to trigonometry to its applications in mechanics are covered across different textbooks along with improper scaffolds makes it an uphill task for students and teachers to develop an integrated understanding of the topics. This spread of the concepts across 8-10 textbooks in a broken manner and the inability to properly scaffold and link these can be seen as an inherent limitation of the textbook. We all are very familiar with the way the content is presented in a modular and linear way as sections and chapters. It is practically impossible for textbooks to present or connect every related topic simultaneously. It becomes daunting for a physics textbook writer to also revise some basic geometry of lines and triangles, trigonometry, coordinate geometry when doing vector addition and resolution, which are very needed when the student learns. The textbook ends up presenting them in smaller chunks and modules in some order spread across math and science/physics textbooks across grades. The very fact of breaking an integrated set of concepts into modules and chunks worsens the problem. Further, the related topics are presented in different textbooks and, the necessary scaffolds and linkages between the topics are absent as is evident from almost 40-50% of the relevant topic links not being made in the textbooks. Thus an integrated understanding of various concepts related to each other cannot be easily made. But that is the best the textbooks can allow.

Lack of geometric manipulation

An interesting pattern emerges as we take a closer look at the nature of the topic links which are not presented. The mode of presentation (explanations or examples) shows certain kind of topics being dealt or not dealt with in each mode. For example, the link between topics of the geometric addition of vectors and the process of resolution, which is crucial for linking the operations on the vectors geometrically and algebraically, is missing. There is a startling gap of example problems which actually allow or require students to add vectors using geometrical methods. Though the fundamental principles behind addition and resolution are the same, there is an increasing tendency to rely on the algebraic modes of operating (like adding) with the vectors as the complexity increases. Any addition of vectors performed is done either using the expression of the cosine law or using the rectangular components, which are again the algebraic modes of adding the vectors. There are not enough problems or activities where students can actually add two vectors just geometrically. The triangle law and parallelogram laws are presented in the explanatory sections to discuss vector-addition. However, once the resolution of vectors is presented, only algebraic mode of adding vectors (using the rectangular components) is emphasized. This is a serious limitation not just with the textbooks that we analysed in detail, but also with other textbooks followed across the globe (Nguyen & Meltzer, 2003). Very few textbooks actually take the efforts to at the least show the process of addition and resolution are interrelated and how the resultant from the geometric addition is identical and equivalent to adding using rectangular components. This is at the crux of all further concepts developed and to enable students to imagine and have a strong and meaningful sense of them. In fact, the NCERT textbook (*NCERT Grade 11 Textbook Physics-1*, 2013) explicitly notes “Although the graphical method of adding vectors helps us in visualising the vectors and the resultant vector, it is sometimes tedious and has limited accuracy. It is much easier to add vectors by combining their respective components.” Similarly, another textbook Halliday et al. (2013), in the chapter on vectors, states that - “Adding vectors geometrically can be tedious. A neater and easier technique involves algebra but requires that the vectors be placed on a rectangular coordinate system.” Though, they attempt to foster some amount of reasoning using geometric methods, like with an example problem, (p44, sample 3.01 where a set of given vectors with some flexibility in direction need to be added, and we need to arrive at the maximum possible magnitude), it is still a constrained one. Actually, adding two vectors geometrically using all the tools of geometric construction (pencil, scale, compass etc) makes the process of geometric addition tedious or less accurate. This explicitly stated limitation in the textbooks, though seeming innocuous, could result in serious consequences. In practice when the geometric mode of reasoning is curbed or not practised, there is a serious chance of limiting the student's imagination, based entirely on algebraic manipulations, which often makes them meaningless. No wonder many students find it difficult to comprehend the algebraic manipulations performed. Also, there is a chance of students and teachers ascribing this as an inherent limitation to the geometric ways of reasoning and visualising.

Limited explanations in applications

The applications of the processes of addition and resolution in mechanics are presented entirely using example problems. And interestingly, these are not presented in explanatory sections. There are no discussions or explanations with enough scaffolds behind the applications in those cases on why and how the processes of addition or resolution are used. So, this boils down to using certain recipes/ procedures (methods like draw free body diagram, resolve in a particular direction, write equations and solve) or formulae, but seldom there are strong reasons presented behind all these steps. For example, in the case of a mass on inclined plane, the choice of the mass for which the free body diagram is made, the explicit steps of making a free body diagram and, the choice of frame of reference to resolve the forces are all left to the student to pick from the patterns or templates in the process of solving problems. But there is little scope for the child to explore the other possible ways of adding and resolving the vector to actually understand and appreciate the rationale behind these choices made. Lack of suitable scaffolds could result in the students resorting to rote methods.

Conclusion

One of the key conjectures that we have, to account for this trending absence of geometric modes of dealing with vectors is the limitation of the paper-based medium of the textbooks. It is very tedious to add vectors geometrically using pen and paper medium as discussed earlier. And often, the logistics around this may put off the key objective of adding the vectors. Whereas with algebraic expressions, the paper-based medium is very flexible in representing and performing various operations, and hence, the dominance of algebra-based reasoning in the textbooks. Ideally, even when we add the vectors using algebraic means, the corresponding spatial significance is expected to be imagined by the students. Adding the vectors and manipulating them in the imagination could make the algebraic manipulations even more meaningful to the students. We are not claiming that imagination is not at all possible using the textbooks as a medium. Some students do manage to imagine and make sense of the algebraic manipulations. But a majority of them rely on memorising algebraic expressions (formulae) and rote learning. In this paper, we confined to the limitations of the textbooks in presenting vectors. Looking at the patterns in the lack of scaffolds and inadequate connections between geometric and algebraic methods of operating on vectors, we claim that these limitations could be rooted in the paper-based medium. However, for this to be established further, we will need to have a closer look at the teaching and learning practices in the classrooms and the patterns in the reasoning abilities of the students. Also, this to some extent is in agreement with the students facing difficulties in vectors that are reported in the earlier studies. However, as a way ahead, we would be looking into the difficulties in students understanding in the Indian context. Also, we will explore if the difficulties in the geometric method of manipulating vectors can be done away with if students are given access to new-age media tools which could overcome some of these limitations of the paper-based medium.

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MATHEMATICS TEACHERS' KNOWLEDGE AND BELIEFS IN PROBLEM SOLVING

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The study reported here is part of a longer study on investigating teachers' horizon content knowledge for teaching mathematics and ways to improve upon it. This paper reports teachers' ways of doing mathematics in context of solving problems and comprehending mathematical solutions. It illustrates challenges that teachers faced due to the atypical representation of the mathematics problems and presents analysis of their use of a mathematical practice, namely "making and using special cases" with narration of emergence of "local" practices for solving these specific problems. This analysis elicits some core knowledge and beliefs of teachers about – mathematical problems, solutions and approaches to problem solving. The paper further discusses how these knowledge and beliefs could leverage practices of teaching mathematics.

Introduction

Many educators have studied the issue of teacher knowledge since Shulman (1986) argued for the specialised content knowledge for teaching. While the educators are agreeing on what constitutes mathematical knowledge for teaching, there is almost no understanding of how this knowledge interacts with teachers' ways of *doing* mathematics. The roots of developing teachers' mathematical knowledge to teach lie in how teachers learned to do mathematics, rather in what mathematics they learned (Ball et al, 2008). Understanding teachers' ways of *doing* mathematics therefore becomes a next step in knowing and understanding teachers' mathematical knowledge for teaching.

Many mathematicians and educators have debated what comprises doing mathematics. Weaving on common understandings across the spectrum – we propose knowledge of mathematics and of mathematical practices, both comprising ways of doing mathematics. Therefore, knowledge of mathematical practices such as justifying, verifying, refuting, estimating, etc., also listed as core competencies in NCF (2005) exhibit doing mathematics. Schoenfeld (1987) showed that the difference in the problem solving performance of mathematicians and the students of mathematics was not in the amount of maths they knew, rather in the mathematical practices they used to solve the problems. The need for knowledge of mathematical practices is not limited to doing mathematics. Ball & Bass (2002) report that teachers often miss mathematical opportunities in their classroom teaching as they lack mathematical sensibilities and knowledge of fundamental mathematical practices. Therefore, unpacking teachers' use of mathematical practices will not only provide a window in knowing their ways of doing mathematics, but will also provide their sense of knowing mathematics for teaching.

The goal of this paper is to highlight teachers' work on solving problems and analysing solutions using mathematical practices. In particular, this paper answers the questions: What practices get constructed when teachers were exposed to formal mathematical practices involved in *doing* mathematics? What knowledge and beliefs teachers exhibit while working on mathematical problems and solutions?

Knowing and doing mathematics

Educationist and mathematicians have emphasised doing mathematics over knowing mathematics. Ball et al (2008) highlight learning to do mathematics as basis for developing mathematical knowledge for teaching. Schoenfeld (1987) in his research on problem solving reports that,

"Mathematicians' success and the students' failure cannot be attributed to a difference in knowledge of subject matter. Indeed the students started off with a clear advantage over the mathematician. They knew all of the procedures required to solve the problem they were given, whereas the mathematician did not remember them out for himself. What made the difference was how the problem solvers made use of what they did know. The students decided to try something and went off on a wild goose chase, never to return. The mathematician tried many approaches, but only briefly if they didn't seem to work." (p. 195).

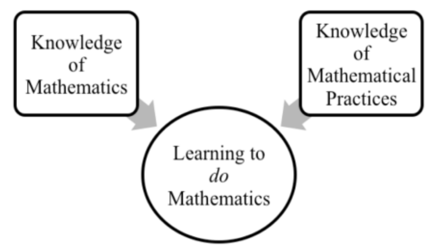

Figure 1: Knowing and Doing Maths

This excerpt illustrates that doing mathematics requires something more than knowing enough mathematics. Schoenfeld summarises that, something like, self-monitoring and self-regulating that helped the mathematicians to solve problems even though the students who had more knowledge to begin with, actually failed. Further, in his study he demonstrated that knowledge of such practices is not organic in nature, rather comes from training to do mathematics. This raises an important question about what entails *doing* mathematics.

The National Council of Teachers of Mathematics (NCTM, 2009) reports that, learning to do mathematics requires knowledge of mathematical practices, a set of activities that include creating mathematical representations, use of mathematical terms, reasoning, and communicating in a mathematical mode. These various accounts that highlight doing mathematics as using mathematical practices in the context of solving problems (see Figure 1), forms a theoretical basis for this study.

The study

To investigate teachers' ways of doing mathematics and use of formal mathematical practices, a four-day workshop was conducted. The reason for using workshop as a setting for investigation came from a pilot study, where teachers were interviewed individually. Teachers found it extremely hard to work without peers and suggested to organise a group problem solving session. The workshop setting was used for eliciting teachers' work on problem solving, and not to teach them how to solve problems. The author played the role of facilitator in the workshop.

The workshop began with discussion of a problem assigned as preparation of the workshop, followed by a brief introduction to Polya's four heuristics. On day 2, based on request – "a help in approaching the problems" from teachers, four mathematical practices were discussed, namely – making and using special cases, making and validating conjectures, finding and proving general pattern and communicating the solutions. The teachers' participation in the workshop involved engagement with four sets of tasks – 1) solving and presenting solutions of mathematical problems, 2) analysing solutions created by other scholars, 3) generating problems and 4) analysing pieces of instruction either in the form of video or transcript to understand problem solving in action. The discussion in the workshop was multilingual – mainly English and Hindi (in the transcriptions, English translations are provided in the bracket). Teachers over the course of 4 days engaged with various mathematical problems that could be solved using school mathematics. The mathematical problems involved a range of mathematical topics including, logic, arithmetic, algebra, geometry and some bit of combinations-permutations.

There were 11 participants in the workshop – 5 women and 6 men teachers. This paper analyses data from teachers' presentation of solutions (task 1) and analysis of solution of others (task 2). Please note that "the others" in the task 2 come from outside of the workshop and include solutions by – students, working mathematicians, and mathematics teachers. The data consists of videos of teacher presentation, oral and written responses and their actual work on solving problems and analysing solutions. For each problem, all 11 solutions were cross-analysed, and filtered for – use of information in the problem, mathematical practices, and formation of the solution. Similarly, analysis of the solution was coded for what teachers attributed as mathematics and mathematical correctness. The presentation in the conference will illustrate more works of teacher than described here in the paper.

Emergence of local practices

In general, the teachers worked on the problems collaboratively (in groups of 2-3) and often presented their solutions in pairs. The data shows a few examples, where different groups of teachers used different mathematical practices to solve a same problem. Often what was observed was, every group used same mathematical practice/s for the given problems, but they differed in their purposes for its use. The following sections describe variation observed in the purposes of using the mathematical practice "making and using special cases", and further narrate the formation of "local" mathematical practices that teachers engaged with. The term "local" has been used in variation in mathematics by different mathematicians. Lakatos (1976) uses the term *local* to indicate limited validity. For example, a *local* proof in Lakatos' sense would be a proof that works for some special cases and yet has not become a global proof. Here the use of *local* is in a similar context, where the practices are emerged catering to the purposes of those specific problems. And even though, such practices would have generic attributes, they seem to be unknown to the teachers at the time of their use. Hence the *local* practice is the term used from point of view of what the teachers generated to solve or analyse the problem successfully.

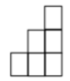

Figure 2: 3-step staircase

Idea of special case was discussed in the context of "square is a special rectangle". Since then, teachers often used this particular practice and described their purposes for the use. Following are the four purposes that teachers named during their presentation: (i) to understand the structure of the problem, (ii) to verify the process of problem solving, (iii) to reach towards a general understanding, and (iv) to quantify the problem. Solutions to staircase problem as cases are discussed below to illustrate teachers' use of the practices.

The problem stated was – if three-step staircase uses the bricks as shown in the figure 2, then how many bricks are needed for n-step staircase. The problem is an analogy problem of – what is the sum of n consecutive natural numbers starting from 1? Although, it was apparent from teachers discussion that they did not notice the analogy, rather imagined the problem as building of stairs, and later began to use 'making and using special cases' practice to arrive at that understanding.

Case 1: Using special cases to understand the structure

A group of teachers preferred to draw examples of the staircase to understand the pattern. Figure 2, depicts the picture that teachers drew on the board. This group described that they used 'special cases to understand the structure of the problem' as they were looking for pattern between the drawing and number of bricks.

> Vinita: We decided to build more staircases. We wanted to see whether we can guess the number of bricks. When we made staircase for 4-steps, *hamai pata chala ke char aur bricks chahiye* [we realised we need four more bricks]. *Waisehi jab 5 ka kiya* [like that when we did 5] we needed 5 more bricks. So we realised as many number of steps we need those many more, those many more bricks than earlier we need.

The teachers' observation above, that the same number of bricks gets added for every next step, is associated with the way they drew the staircase. The teachers understood that for every next step in the staircase, they had to add those many bricks.

When this group proceeded to find out how many steps they need for n-step staircase, they reached to the conclusion that it is n more than the bricks required for n – 1 step staircase. Even though these teachers continued deducting number of bricks for n – 1 step staircase and then for n – 2 and so on, they never reached to a generalised answer. There answer was a recursive one, n bricks more than the number of bricks required to built n – 1 step staircase.

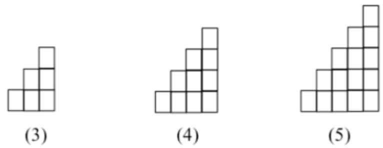

Figure 3: Understand the structure

Case 2: Using special cases to verify the process of problem solving

Some groups immediately began counting the number of bricks. The first question they asked themselves was how many bricks for 4-step staircase, how many for 5-step staircase. Even though the teachers' approach in this group, seems similar to the one above, these teachers did not make any drawings of the staircase, rather they made a table (See Table 1).

Number of steps in the staircase	Total number of bricks required
3	6
4	10
5	15
6	21
10	55
15	120

Table 1: Verify the process

This group too, like the earlier saw the recursive relationship.

However, they chose to pick random cases, and not the consecutive ones to see how many bricks it requires. When asked why they chose random numbers and not consecutive, the group said that, they knew that there exist a relationship between the steps and the number of bricks and consecutive examples were not helping them to see that. Although, the groups who used the tables, couldn't see the analogy to sum of natural numbers or never came up with a generalised formula, the variation in the use of the special case was made to "break-free" from the recursive pattern.

Case 3: Use special cases to generalise the process of problem solving

This group used special case to count the number of bricks differently. Two of the groups used this method of counting. These teachers mentioned that, if one wants to find the number of bricks in a given staircase one needs to understand how the staircase is built.

Jennie: See if I have to build a 7-step staircase, what will I do? I will first lay 7 bricks, then 6 bricks, then 5, then 4, then 3, then 2 and then finally one brick [she drew bricks like a line and wrote numbers next to it]. So you see, basically we need bricks in this order, 7, 6, 5, 4, 3, 2, 1. *Toh 7-step staircase banane mai hame yeh sabhi bricks lagenge.* [This means we will need all these bricks to make 7-step staircase].

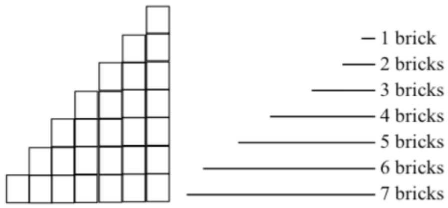

Figure 4: Generalizing the process of problem solving

Rahul: So if you want to know how many bricks we need for 7-step stair case, it is 7 + 6 + 5 + 4 + 3 + 2 + 1. This way for 10-step staircase it is 10 + 9 + 8… up to 1. And for n-step staircase, it will be n + (n – 1) + (n – 2) + … and so on up to 1.

Actually Jennie and Rahul worked in different groups, however as Jennie started presenting, Rahul joined her to provide general structure of the argument. The way Jennie wrote bricks from 7 to 1, Rahul wrote from n to 1. These groups' ideas were also associated with the way they constructed the figure. Figure 4 shows what they drew on board while presenting. All the teachers appreciated these teachers' use of special case and how they generalised the pattern.

Case 4: Using special cases for quantification of problems

This particular group chose to change the problem itself. The statement of problem that said – "if three-step staircase uses the bricks as shown in the figure 2, then how many bricks are needed for n-step staircase" was changed to "if three-step problem requires 6 bricks, how many bricks are needed for 26 step staircase." This interesting shift from a general n to specific n = 26, changed the entire approach towards solving the problem. The language of the problem initially tempted the teachers to use unitary method (find value for one unit). They wrongly concluded that one-step staircase requires 2 bricks (6 divided by 3), and therefore, for 26, it would be 26 times 2, which is 52. It took some discussion in the group to realise that the structure of the problem is different, and finally when they made the table for number of steps with required number of bricks, they were unable to find any relation that would explain the growth in the number of bricks.

Quantifying the given problem did not help the teachers in this case, however there were other problems, Naik & Khan (2015) where teachers successfully used the process of quantification.

Same practice different purposes

The formation of customised practices which the teachers themselves preferred to call as "local practices", opens up an unfamiliar territory of what we know about teachers' mathematical knowledge. There are two possible explanations to what is observed. One – what teachers mainly referred as achieving the special cases in all the examples above is that, converting a verbal problem into a problem of numbers. Except in one case where the problem was converted to pattern of pictures. This approach of digitising the problem aligns with the view that mathematics, especially the school mathematics is about numbers. The school assessment too is about the numerical answer or steps, and not of the logical thinking behind it. Therefore reaching to the numbers seems to be a priority in teachers' work. Quantifying the problem immediately brought the teachers in a familiar territory, thinking it as a problem of unitary method – a sequence that has a constant rate. But, identifying it as an unitary situation constrained some teachers to see the general structure of the problem (case 4) and their mathematical knowledge was challenged. Whereas the structural understanding (Case 3) that was used by some groups, elicited the general structure. An explanation of these multiple purposes behind specialisation comes from Lakatos' (1976) idea of local and global examples and counter examples. Lakatos, describes how one first understands or attempts a proof by digitising or sketching the statement of theorem using examples that are true in limited conditions, and therefore disproving is synonymous to finding a global counter example. With that lens, teachers' ways of *doing* mathematics are limited to finding *local* solutions. In all the examples above, none of the groups could reach to the generalised form of the solution. Does the inability in reaching or comprehending the generalised form of both the problems discussed in the paper, indicate that the teachers in the study lack global sense of mathematics? These results taken as a whole probe further investigation – why the teachers tend to be or happy with obtaining *local* solutions? Or a better-phrased question would be – why the teachers do not see a generalised logical form of mathematical thinking as mathematics? A further strengthening evidence regarding what is considered as mathematics by teachers came from their analysis of solutions that were given by others.

Analysing solutions

Each teacher analysed solutions to five problems. These solutions were generated by different scholars – such as mathematicians, maths teachers, and students. One of the immediate discussion the teachers did was on deciding whose solution it might be – a student, teacher or mathematician. They started saying things such as this must be some students' solution as it does not use proper ways of mathematics, or this must be some teachers' solution as it refers to remembering other problem similar to this one. Teachers judgements not only indicated what they believe our students or teachers can do, but it also exhibited their beliefs about what is appropriate mathematics and what consists of a mathematical solution. Out of 55 instances of solutions that were given by the mathematicians and analysed by the teachers only 11 were counted as some sort of a mathematical solution by the teachers, the rest 44 were labelled as non-mathematical solutions. We discuss teachers' responses on one such problem and how they understood the mathematics present in the solution. Given below is one of the solutions the teacher analysed. This particular solution was given by a practicing mathematician from a reputed institute in India.

A printer only prints the page numbers of a book. While doing so printer uses 999 digits. What is the last page number of the numbered pages?

First thing that comes to my mind is that the number of pages must be less than 999 (almost obvious, but is a useful information). Between 1 and 999, there are single digit numbers double digit numbers and three-digit numbers. By simple intuitive estimation, the number pages must be in three digits, which means we all the single and double digits numbers are there as page numbers. We have to count how many of them are there. There are 9 single digit numbers, 90 double digit numbers. These account for 9 + 2*90 = 189 digits. So we are left with 810 digits (which all come from three digit numbers). Therefore there must be 810/3 = 270 3-digit numbers. Three digit numbers start with 100, so the last page should be 369.

An immediate response that all the teachers gave for this solution was to tag this one as not-appropriate mathematical solution. The teachers expected that the solution should have begun with assuming x number of pages in the book and then formulate some equation using given information. When asked about the first conjecture the solution presents – the number must be less that 999, teachers took a moment, but agreed to conjecture. They thought this could have been written as $x < 999$; and then give reason why that is the case. The teachers said this solution cannot be by a mathematician or a maths teacher. When asked what made them conclude this, they pointed out certain phrases present in the solution, such as – intuitive estimation, have to count, etc. as non-mathematical. Teachers appreciated the end part of the solution – most of them said "it is logical", but found it too *textual*. When asked what is problem with a textual solution, this is what the teachers said.

> Shobha: In examination, the students get marks for each step. This solution is like an essay. Nobody will read this response. We look for steps in the solution.
>
> Sabina: Mathematics is a language in itself. It doesn't require any language. That is why you can understand math even if it is in different language.

Teachers gave different indicators for what makes something mathematical. Most of it might be coming from what is presented in the textbooks. The solution requires steps, it needs to have some variables, finally the answer needs to be reported in the context of the question, these were some standard criteria which teachers cited and we often see them in school textbooks.

Conclusions & Implications

Both analysis showed that teachers count numbers, symbols, expression, equations, etc. as mathematical, whereas logic was seen as important part of doing mathematics but not essential. A symbolic representation makes something mathematical, not the logic or deductions that were made in the solution. In many problems the teachers were stuck, and they reported not knowing where to begin. The atypical problems did not always allow them to assume something as x. In the tea and *sharabat* problem they assumed quantity of tea as x and quantity of juice as y but found that the given information is not enough to form an equation using x and y. The similar concerns were raised for the page number problem, staircase problem, etc. What makes a problem mathematical or a solution mathematical, is understood in a narrow sense by the teachers – mainly by the way it is presented, whether *steps* are part of the solution or not. Computation was seen as the core part of a mathematical solution. An estimated guess based on mathematical properties of numbers was not mathematical for these teachers. On the other hand, *doing* mathematics at the graduate level and at the level of mathematicians, as Schoenfeld (2010) reports, has components of logic, practices, and deductions. These constrained views of mathematics, limit teachers' acceptance of students' mathematical ideas – that are often present in the verbalised or contextualised form.

Said this, the teachers' use of mathematical practices, and negotiating those to make them suitable for their specific use in the problem, creates a picture of hope. The teachers themselves are needed to experience *doing* mathematics in the sense that frees them from the textbook representation and narrow evaluation standards. Teachers knowing certain concepts is not enough to broaden their views of what constitutes *doing* mathematics. Additionally, the problems that were given to teachers had opportunities that many textbook problems don't have. They were atypical, away from standard structures, and involved simple logical understanding and *unpacking* of the information – again not in typical symbolic form but in the form of pictures or diagrams. To understand and include students' natural ways of doing mathematics, the teachers need to experience the same by entering into unfamiliar territories, such as the atypical problems they solved in this study. Solving these problems did not involve employing a certain formula or forming an equation, it involved thinking about representation, creating access in to what the question is asking. I believe that even though there are studies that investigate teachers' understanding of students' problem solving; more studies are needed that understand link between teachers' ways of doing mathematics with their ways of teaching.

Acknowledgements

I thank Prof. Subramaniam at HBCSE for giving me this opportunity to work with teachers on problem solving and continue my research on mathematical knowledge for teaching. I also thank, Tuba Khan, a former project staff at the centre who provided tremendous help in organising and conducting this workshop. All the problems, solutions and videos of teaching that were used in this study are available for anyone to use at: mathedu.hbcse.tifr.res.in

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ASSESSING MATHEMATICAL MODELLING

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In many countries modelling is an integral part of mathematics instruction by now. At all levels of education an increase of modelling activities can be recorded. To implement the standards of educational policy there is a need for suitable instruments and methods to assess them. There are several well-elaborated tools in the field of research assessing performance which are often based on a complicated background. When it comes to assessment in the field of schooling as an instrument for teachers and feedback for students, different standards must be imposed. As part of a study an assessment method has been set up and analysed by comparing empirical and theoretical complexity of mathematical modelling tasks. The present paper focuses on the explanation and interpretation of the empirical complexity and its coherence with assessment practices in school.

Introduction

Comparative studies such as PISA or TIMSS and national curricula worldwide integrate modelling as important competence. There is an increase of modelling projects or modelling activities at all levels of education (Galbraith, 2007). Educational policy demands for reasonable performance evaluation but also in school modelling must be part of assessment to be taken seriously (Maaß, 2007, S. 39). Modelling must be relevant in grading to be seen as an essential part of education (Hall, 1984). Or, to put it in the words of Niss, “What you assess is what you get”(Niss, 1993, p. 43).

Especially when it comes to mathematical modelling in school, the mathematics community is still discussing the format of assessment. Open to debate are written reports, term papers, portfolios, presentations, panel discussions to name but a few (Niss M. , 1993, S. 17 ff.).In addition to this, studies revealed a variety of problems students and teachers are faced with when solving or teaching modelling tasks. Besides organisational and material-oriented issues, a variety of problems mentioned by teachers seem to be traceable to the openness of the task format and the associated large task space. Lack of predictability, assessment and the time factor are aspects mentioned by teachers (Schmidt, 2010). Assessment of modelling tasks is a major challenge which often hinders mathematics teachers in integrating modelling in mathematics classes (ibid.). Atrigger can be seen in the variety of solution approaches of modelling tasks. Despite the claims of educational policy, these problems contribute to a still low percentage of modelling tasks in everyday school life (Blum & Borromeo Ferri, 2009).

A study of Reit (2016) ties in at this point by setting up and investigating a method to assess modelling tasks on the basis of their complexity by analysing solution approaches of students. The empirical complexity representing the assessment of student solutions on basis of a rubric is the focus of the present paper.

Theoretical framework

When assessing mathematics tasks, the solutions' numerical value is often taken as predominant indicator of a right or wrong solution. When dealing with modelling tasks, however, it is not meaningful to assess a solutions' numerical value due to the multiple solution- nature of modelling tasks. A common opinion is that modelling tasks cannot be assessed as objectively as traditional task formats (Spandaw & Zwaneveld, 2010). These traditional task formats were taken as a starting point for further investigations towards a theoretically well-conceived and a, for teachers, manageable assessment procedure.

A common assessment procedure of mathematics teachers when assessing traditional task formats, is to set up a rubric in advance in the form of a sample solution, pointing out the necessary intermediate steps of a solution. These intermediate steps are then scored. As a result, tasks with many steps are given higher scores than those with less steps. By implication this means that tasks with a higher maximal score are usually rated as more complex and time consuming which is, in turn, crucial for the whole construction of a written examination. In summary, task complexity is crucial to correctly estimate complexity and processing time, two important factors of an examination. Due to the openness of modelling tasks, solutions can vary widely such that there is no unique sample solution which can serve as a template for a rubric. This complicates an objective assessment.

In the following it will be discussed whether there is scientific evidence that the identification of steps in a solution can serve as a basis for assessment and, if so, how this procedure can be transferred to modelling tasks.

Intermediate steps and cognitive structures

The common procedure of mathematics teachers mentioned above has similarities with structural considerations within the field of word problems. Breidenbach (1969) looks at the structural-substantial complexity of a word problem e.g. to decide about its complexity. For example, in the task illustrated in Figure 1 there are two variables in the first step from which a third variable (Figure 1: daily requirement in total) can be uniquely determined by one operation (Figure 1: multiplication). Breidenbach named such tasks "Simplex". A linking of several Simplex's in the solution process is called a "Komplex". Further developments by Winter and Ziegler (1969) lead to the arithmetic tree (see Figure 1) which is still used in mathematics textbooks today.

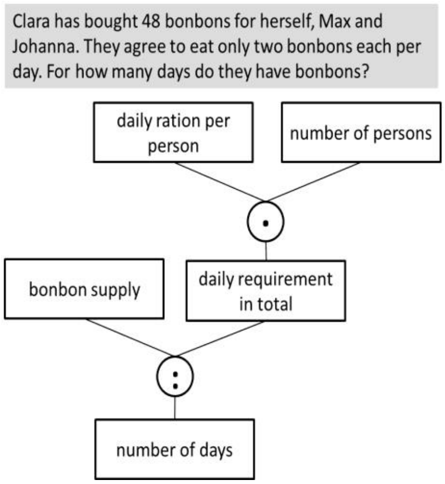


Figure Error! No text of specified style in document.**:** Arithmetic tree of an exemplary

An obvious but so far empirically not validated conclusion is that a larger number of Simplex's and a more complicated nesting of them, have an effect on the solution complexity (Graumann 2002). Cohors-Fresenborg, Sjuts, and Sommer (2004) describe task complexity, inter alia, by the criterion *cognitive complexity* of thought processes. This allows for simultaneity or nesting of thought steps. In this context Kaune (2000) also distinguishes between two aspects of cognitive complexity. These are firstly the processing of multiple information within one thought step, and secondly, the influence of previous information.

The coherence of structural considerations and cognitive theories plays an important role. In their study, Fletcher and Bloom (1988) assume that text comprehension is a problem-solving process, where the reader must find a causal chain to link the start and the end of a text. In order to form these links, they furthermore assume that the information must be simultaneously kept in the working memory of the problem solver. Results of their study show that it is important for readers to have access to the direct preceding information before proceeding in the causal chain. It can be concluded that the task of the working memory is to keep key information available. This is necessary to link old and new information (Baumann 2000). By relating these findings to structural considerations of a solution approach represented as an arithmetic tree, statements can be made about its cognitive complexity. On the one hand, an arithmetic tree-like structure (Figure 1) can be interpreted as a causal chain since the start (given information in the task text) and end (solution of the task) is linked by chain links (intermediate steps in the solution process). On the other hand, direct predecessors can be identified as relevant intermediate steps. Thus, it can be concluded that the previous intermediate step must be kept active in the working memory to master the following step. The assumption that the mental processing capacity is limited (Sweller 1988) leads to the conclusion that a multitude of information which has to be kept active at the same time, can complicate the solution process. Thus, it can be concluded that the load of the working memory is dependent on the number of intermediate steps necessary to master the current intermediate step in the problem-solving process. This means that the load of the working memory increases with the increasing number of information needed at the respective points in the solution process.

With regard to the above the study of Reit (2016) established a framework to structurally analyze student solutions of modelling tasks with the aim to determine its complexity. It is assumed that the number of sequential and parallel thought operations provides information about the cognitive complexity of a solution approach.

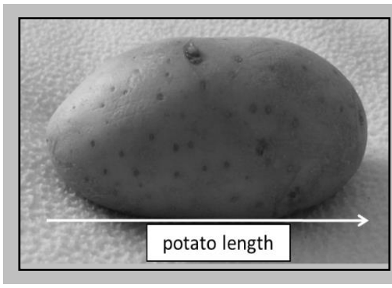
The considerations from above justify the use of intermediate steps as template for a rubric and, furthermore, as an indicator for the complexity of solution approaches when analyzing the nesting of steps within a solution approach.

Method

A part of the study of Reit (2016) was to assess student's modelling solutions as a measure for the empirical complexity of a task. The procedure of setting up a rubric was based on the assessment practice with traditional task formats, as the identification of intermediate steps for assessment is justifiable. An empirical study was conducted with 1800 student solutions of previously developed modelling tasks. The aim of this phase of the study was firstly to identify different student solutions and secondly to set up a rubric for these solutions according to which the solutions were scored. On the basis of the statements in the theoretical framework a so-called thought structure analysis was developed. Therethe structure of various solution approaches was analysed by identifying their specific thought operations. These thought operations can be seen as necessary intermediate steps of a solution and, thus, served as a basis for the rubrics.

Modelling tasks

For this study five modelling tasks were developed according to predefined criteria (see Reit and Ludwig 2015). Three of these five tasks were randomly placed in a booklet which was distributed to the students. 1800 grade 9 students (15 years of age) from selected German grammar schools took part and completed a booklet. Each student was asked to solve the tasks individually. The total processing time for a booklet was 45 minutes. An example of one of the five modelling tasks is shown below. The students were asked to mathematically estimate the number of French fries which can be cut out of a single potato.



Industrial manufactured French fries are supposed to be equal in size and the single sticks are cut out lengthwise. Therefore, not the whole potato can be used. The potatoes look similar to the picture alongside. They are regularly formed and approximately 10 cm in length. How many French fries can be obtained from one potato?

Reason mathematically.

Figure 2: Modelling task potato

Thought structure analysis

All student solutions of every modelling task were analysed and solution approaches within tasks were identified. On the one hand, this classification was based on the mathematical model used and on the other hand on the solution process, which can be different although the same mathematical model was applied. Each solution approach has a specific structure which can be revealed by dismantling the solution approach into its single thought operations (Reit & Ludwig, 2015, p.918). In this context, the term *thought operation* was defined as “a necessary (intermediate) result which is obtained directly (without intermediate calculations) from one or several (initial) data” (ibid.). Within solution approaches, single thought operations were identified and arranged as a kind of arithmetic tree which finally represents the thought structure of the respective solution approach (Figure 3).

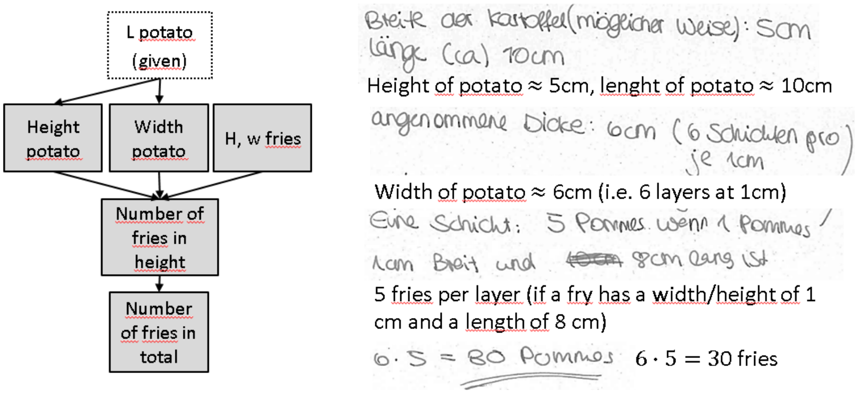


Figure 3: Student solution of modelling task potato (solution approach layer) (right) together with its thought structure (left)

Figure 3 illustrates a student solution of modelling task potato representing solution approach layer and the corresponding thought structure. The thought structure pictures the thought operations needed for the next step in the solution.

In the thought structure of Figure 3 it is obvious that the estimation of height and width of fries was pooled as one thought operation. To ensure comparability of thought operations similar calculation steps which refer to the same object are seen as one thought operation. In case of the fries a square base is assumed by the students. After having made an estimation of the height, the determination of the width does not justify a separate thought operation.

The rubric

The average score of a solution approach was taken as a measure for the empirical complexity. This is based on the assumption that the higher the students scored using a specific solution approach, the easier it is and vice-versa. Rubrics were developed to assess student solutions and finally, to determine the empirical complexity. Following the usual assessment practice in school and in line with the theoretical considerations from the previous chapter, thought structures were taken as a basis for assessment. Every thought operation can be seen as necessary intermediate step. According to whether a thought operation was realized correctly, with mistakes or not at all, it has been awarded with 1, 0.5 or 0 credits (Reit, 2016, pp 132). Consequential errors were taken into account, to maintain the process-oriented intention of modelling tasks also during the assessment. The procedure can be summarized (ibid.):

1 credit	The thought operation was realized correct
0.5 credits	The thought operation was realized with (tolerable) mistakes
0 credits	The thought operation was not realized or it was realized with heavy mistakes suggesting that the intention of the thought operation was not understood

To compare solution approaches, the total score was normalized and put in percentage indicating to what extent the student has solved the task.

A sample solution for every solution approach was set up and used to formulate a rubric (see Reit, 2016, p. 194 ff.). The students used four differentiable solution approaches to solve modelling task *potato*. Following the thought structure and the sample solution of solution approach *layer* (Figure 3) the rubric of Table 1 was set up. Two independent raters assessed all student solutions following the elaborated rubrics.

Height of potato	
1	Scaled calculation of height using the given length (allowing for residues)
0.5	Still reasonable estimation of height (e.g. 4 cm if measured from the picture without scaling)
Width of potato	
1	Reasonable estimation (width=height) (allowing for residues)
0.5	Deviation from above (+/- 1 cm)

Height and width of fries	
1	Reasonable estimation (0.5 – 1.5 cm)
0.5	e.g. estimation of length of fries of 10 cm (no residues of potato taken into account)
Number of fries in height and width	
1	Mathematical correct calculation (rounded off solution)
0.5	Small calculation errors (e.g. no rounded off solution or fries punched out vertically)
Total number of fries	
1	Mathematical correct calculation
0.5	Small calculation errors (e.g. no consideration of remains, if a fry-length of 10 cm was assumed)
5	**Maximum score**

Table 1: Rubric of solution approach layer of modelling task potato (cf. Figure 3)

The application of the rubric is exemplified by two student solutions of solution approach layer (Figure 3 and Figure 4). The student solution of Figure 4 assumes a potato length of 10 cm, as it was given by the task text, a height of 5 cm from which 4 cm can be used to ensure that all punched out fries have the same length. This last consideration goes in the right direction but disregards necessary potato residues in the length. The fries have a width of 0.5 cm, whereby the student probably assumes a square base. During his further calculation, the student calculates the number of fries per (vertical) layer (4:0.5=8) and multiplies this result by 2, "because of the width" of the potato, which is actually too less. In large parts, a successful solution applying the idea of layers.

The solution in Figure 3 shows a 100%-solution in terms of a mathematical correct implementation of the corresponding thought operations in line with the rubric (Table 1).

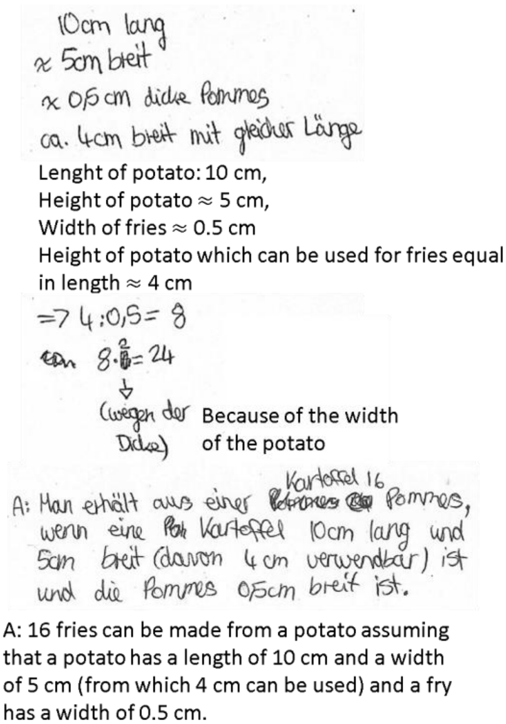


Figure 4: Student solution using solution approach layer scoring 80%

Results

All student solutions were rated by two independent raters according to the rubrics. Kendall's τ lay between 0.628 and 1 which suggests a good inter-rater reliability.
It is noticeable that also unrewarding solution approaches scored. This was the case, if the student started

with basically reasonable calculations but terminated before a target-aimed direction could be identified. In Table 2, it can be seen that the scoring of unrewarding solution approaches fluctuates and a statistical analysis confirms a significant difference between the modelling tasks ($\chi^2=80.341$, $p<0.001$). Unrewarding solution approaches of modelling task *tennis racket* scored significantly worst ($p<0.001$).

Taj Mahal	34%	Tennis racket	35%	**Potato**	**37%**
Area	63%	Rectangle	70%	Volume	64%
Rows/columns	67%	Function I	44%	**Layer**	**77%**
Level	49%	Function II	41%	Area	58%
				Cylinder	50%
unrewarding	8%	unrewarding	2%	unrewarding	12%

Coke bottle	38%	Bridge	50%
Cylinder	66%	Area	78%
Cuboid	70%	Per unit area	69%
Decomposition	75%	Rows/columns	75%
		Per m²	67%
unrewarding	7%	unrewarding	9%

Table 2: Average percental score

With regard to the average score of a modelling task (as average across the solution approaches) the result of modelling task bridge stands out. Whereas all other modelling tasks reach an average score between 35% and 38 %, modelling task *bridge* scored 50%. There are significant differences between all modelling tasks ($\chi^2=33.748$, $p<0.001$) and especially modelling task *bridge* performs significantly better than *tennis racket* and *coke bottle* ($p<0.001$).

Analysis of results

By comparing the unrewarding solution approaches there is an obvious difference between the scores of modelling task *tennis racket* and modelling task *potato*. This can be associated with the structure of the task itself and the solutions in general. Modelling task *tennis racket*, where the question was to calculate the length of string needed for a pictured racket, may have somehow promoted acting without due consideration. Many unrewarding solutions of modelling task *tennis racket* calculated the racket area which led in most cases in a dead end. This suggests the assumption of an inconsiderate action in terms of having done *something* mathematical. In contrast, the task text of modelling task *potato* seemed to be clearer and to lead to a target-aimed direction. This can be seen in the fact that many of the unrewarding solution approaches could be theoretically continued to arrive at a reasonable solution. An unrewarding solution approaches showed elementary but target aimed stages which, however, were not pursued far enough.

The high solution rate of modelling task *bridge* suggests being easier accessible which is also supported by the complexity of the task text (Reit, 2016, pp. 103). The student-friendly context, the plain language style of the task text with easier linguistic terminology and the clear representation of the data may explain the differences.

Discussion & Outlook

In view of a still low percentage of modelling tasks in everyday school practice and the fact that the question of assessment hinders mathematics teachers to implement modelling in their classes, there is a strong need for a manageable instrument. The assessment of modelling tasks suggested by the rubrics presented in the paper are based on thought structures of actual student solutions. In contrast to many other assessment approaches for modelling tasks, the method of thought structures is close to the assessment practice of mathematics teachers which ensures manageability in everyday school life. The is not least verified by the good interrater reliability. Furthermore, transparency is ensured since the rubrics originate from what students did. In summary, the thought structure analysis turns out to be a promising assessment procedure.

An important issue is whether the empirical difficulty takes account of the complexity of solution approaches. The complexity of a solution approach should be reflected in the solution rate. The question arises if and how thought structures can take account of that fact. In the study of Reit (2016) the substantive and statistical suitability of the thought structure analysis together with its underlying cognitive and structural assumptions was investigated. The results indicate that parallel thought operations in a thought structure complicate a solution approach. However, the widespread procedure of mathematics teachers assessing intermediate steps in a purely linear way also led to good results.

In view of the applicability of rubrics based on thought structures in everyday school live there is a need for further research. Particularly with regard to the fact that assessment is a great challenge for teachers in the context of modelling, the study provides promising approaches and gives rise for continuing investigations to that point.

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BRINGING EXCITEMENT INTO CHEMISTRY THROUGH ACTION RESEARCH

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In his eighth year of teaching, a chemistry teacher in a residential school confronted the monotony and tediousness that he experienced while teaching. He also recognized the challenge of getting his students to enjoy learning chemistry. This paper describes his year-long action research that succeeded in turning things around – slowly but remarkably – from teaching passive, disinterested students to engaging with a bunch of enthusiastic and excited learners. His action research aimed to bring in a greater number of "AHA" moments in his students, during their learning of chemistry. By the end of his journey, he had revisited some of his prior assumptions, gained several insights into his approach and noted that most of his students now enjoyed his classes. Above all, he had himself experienced "AHA" moments. The process of facilitation of his action research is described as also the evidence that the researcher gathered to validate its conclusion. This work attempts to overturn the popular assumption that an experienced teacher cannot significantly alter his/her teaching practice.

Introduction

An experienced teacher of chemistry in a residential school undertook action research (AR) in his eighth year of teaching. He was prompted to do so because of two reasons: first, his own experience of increasing monotony in teaching the subject, as well as the difficulty experienced by his students in learning it – a fact that had been brought to his notice by some students as well as the school principal. The latter requested the second author of this paper to facilitate his AR so as to bring about enjoyable teaching-learning of chemistry for teacher and students. This work was carried out over a period of a little over one academic year. Hereafter, the teacher will be referred to as the *teacher/researcher*, and the other author as the *facilitator*.

AR has been successfully employed to turn teachers into reflective practitioners (Nunan 1989; Elliott, 1991; Perrett, 2003; Raghavan & Sood, 2015). Although this teacher was himself very enthused about chemistry, he was acutely aware of the fact that his students did not share his love for the subject and he could also see that he had settled into a mechanical mode of transaction. Despite his keen desire to effect a change, he was unclear about the way forward - and so AR was deemed an apt method to employ. The work of Humerick (2002), Avergil et al (2012), Tolentino et al (2009) and Dori & Barak (2001), amongst several others was referred to by the teacher-researcher so as to draw from their ideas and enliven his teaching of chemistry.

Methodology

Beginning with an introduction of the framework of AR (see Figure 1) to the researcher by the facilitator, a sustained engagement between this researcher-facilitator duo began. The nature of engagement was one face-to-face meeting every month, a classroom observation by the facilitator [the teacher would know when the facilitator was going to observe his class] followed by sharing of her observations with the teacher-researcher in a face-to-face meeting. A couple of emails were exchanged roughly every quarter. The facilitator factored this researcher's newness to research into her mode of facilitation, by suggesting structured documentation only six months into his research, and referred a few research papers for him to read only at the very end of his AR.

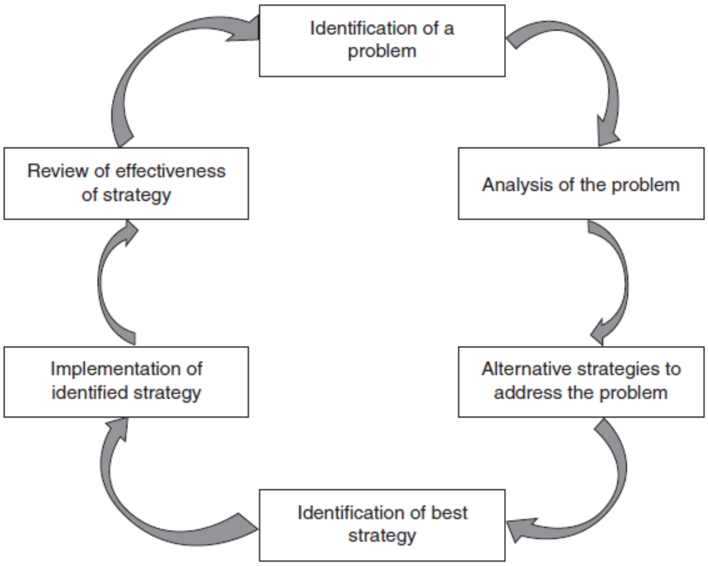

Figure 1: Framework of Action Research (Raghavan & Sood, 2015)

Identification of the AR problem

The researcher began by noting as follows: *Although I believe that I have always tried to reach out to the entire class, I often get the feeling that I fail. I also experience a sense of monotony and tediousness in transacting the subject. I need to make it more interesting - for me as well as for my students.*

Through the course of the AR, the facilitator observed about twelve classes, during each of which she noted her observations. As rapport between the duo increased, the facilitator began to share more and more feedback with the teacher (during the monthly meetings), who then took note of her suggestions and began to act on them. In her very first classroom observation, she made a note of his tendency to *"go back and forth, the thought sequence is not clear and logical. He is not cognizant of the priority of concepts, or the flow of logical thinking."* She did not share this feedback with the teacher just yet, however.

Framing the problem

After the second meeting, the facilitator noted: *It took some discussion for a concrete problem to emerge. The teacher slowly framed his AR problem thus: How can I bring in a maximum number of AHA moments for as many students as possible, in each class that I teach? I was also touched by his honesty in owning up to having a poor understanding of electrolysis – probably one among many topics, he admitted. Which teacher owns up readily to not knowing something properly? He admitted that he had not been taught that topic well – having had limited exposure. With all these limitations, I am struck by his zeal to be a good teacher.*

Analysing the problem

The facilitator then led the researcher through a process of analysing the AR problem, through a set of questions tabulated below:

Question posed by facilitator	Answer given by researcher
What is meant by an "AHA" moment?	"The sudden understanding or grasp of a concept is often described as an 'aha' moment – An event that is typically rewarding and pleasurable. Usually, the insights remain in our memory as lasting impressions." Rick Nauvert
Why are hardly any students currently experiencing these moments?	I often solicited student feedback after tests. Many students in my class would frequently say that they found it difficult to remember so many facts, from a vast syllabus. Many also perceive Chemistry to be abstract - requiring visualization. It puts many people off. Metallurgy, numerical problems, mole concept, etc. are seen to be dull and boring, and valencies, chemical formulae and chemical equations difficult to memorize.
What is preventing these moments from occurring?	I find that I am mostly unable to gauge interest levels of students so as to then engage them. Sometimes, I notice that students do not like to get involved in activities, especially if they are not hands-on. It is even more difficult to get them engaged in written work. But then, every topic does not lend itself to hands-on activities e.g. Atom, Molecule, Mole, etc.

Table 1: Analysis of AR problem

As can be seen above, the process of analysing the issue led the teacher to recognize his own inability to gauge student interest levels.

Identification & implementation of strategies

As the teacher continued to share his observations of his teaching methodology, the space for examining them without judgment slowly opened up. The teacher began noting his own pattern of teaching in his emails to the facilitator: *I could see that I tended to jump from one idea to the next and often, children were unable to keep pace with me. Sometimes, while teaching, I would assume that there was no need to explain each step as these children know quite a lot about the subject. But in so* *doing, a certain sequential logic and flow would be missing.* Thus, the teacher had now realised for him what the facilitator had initially noted (but had then refrained from sharing with him). Interestingly, this was not the first instance of the researcher being made aware of missing steps in his sequential logic. By his own admission, peer feedback had been given to him before he embarked on AR: *"One of my fellow teachers observed my class and alerted me. He told me that there was no continuity or flow in my teaching."* However, with the framework of AR, he slowly began to feel empowered to *actually address this gap*. Strategies that were discussed during the monthly meetings with the facilitator began to play out in the teacher's classes – and he could now slowly see their impact. The facilitator and researcher came up with the following list of strategies:

1. Introducing concepts from their historical origin
2. Use of concept maps
3. Hands-on activities
4. Audio visual tools
5. Projects to motivate disinterested students

Slowly, the teacher-researcher began implementing each of these strategies.

Incorporating the history of science: While teaching the Kelvin Scale of temperature, the teacher noted thus: *I started the lesson called Study of Gas Laws by showing videos*[1] *on how scientists derived the value of absolute temperature as* -27^{o} *Celsius. I found that students were interested, as they appreciated the efforts of different scientists.*

Use of concept maps: The facilitator suggested that the teacher draw up a concept map while preparing the lesson plan, so as to address the missing steps in logical sequence. The teacher shared with the facilitator his concept map for balancing chemical equations, and this is presented below to exemplify the teacher's altered lesson planning with a concept map:

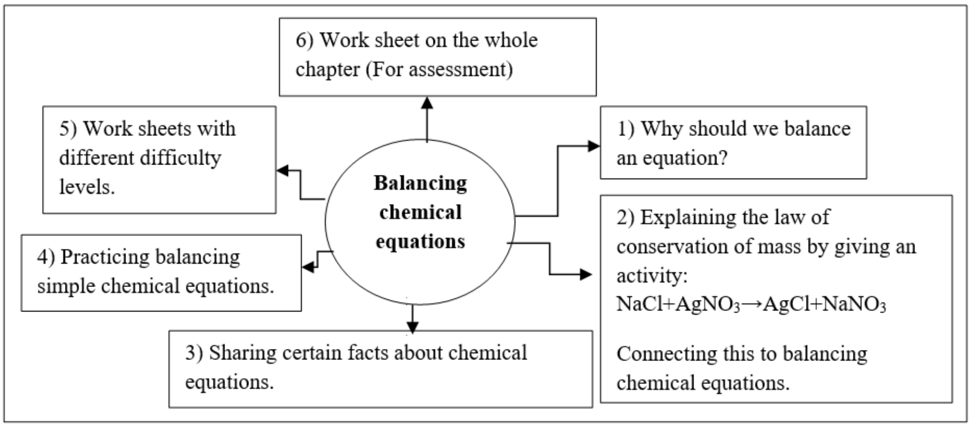

Figure 2: Concept map for balancing chemical equations

[1] https://www.youtube.com/watch?v=zY5OwnggnUE, https://www.youtube.com/watch?v=wl66BIgfHGk, https://www.youtube.com/watch?v=gBWn00X-1tQ, https://www.youtube.com/watch?v=W3Lk9aDMqpM, https://www.youtube.com/watch?v=HqbcZz-p7lQ

The teacher soon noted the power of drawing concept maps thus: *Once I started using concept maps, I felt that I wasn't missing the logical sequence of concepts. It also helped me to cross check whether I had missed out any concept while delivering the lecture. I also made my students practice drawing such concept maps for the chapters which they found difficult. Two students benefited noticeably from this exercise.*

Hands-on activity: The teacher transacted the class on balancing chemical equations by having students actually weigh reactants (NaCl and $AgNO_3$) and products (AgCl and $NaNO_3$) before and after mixing, *for them to be convinced* of the law of conservation of mass – the basis of balancing a chemical equation. He recalled that before embarking on AR, he would simply demonstrate this mass conservation to the entire class, but that he now felt compelled *to bring it directly into the field of experience of each student*. *"If I have them experience the fact first, and then go into the law or definition, I feel it works better,"* he declared. The facilitator noted that this was the teacher's own 'Aha' moment.

Figure 3: Student seeing relationship between temperature & volume

The teacher then documented thus: *After I saw the success of the above strategy, I began to employ more hands-on activities. I found that students got firsthand experience which helped them draw their own conclusions, instead of merely going by the textbook. Class IX was asked to play with a cycle pump, a bottle, a syringe and a balloon. When they pumped air into the bottle as shown below, the volume of air in the syringe decreased and the balloon got compressed. Now the students drew their own conclusions about the relationship between pressure and volume. Every student was involved and subsequently they were able to draw a graph and define Boyle's law on their own.*

Students went on to perform activities like making voltaic cells, observing how a dented tennis ball loses its dent upon heating, etc. Chemistry classes changed from lecture-demonstrations to interactive sessions. More importantly, the teacher's own reflections about his altered approach brought home to him many nuances of the teaching-learning process: *Previously, I used to show animations in the computer centre to help students see how these characteristics of gases are related to each other. I found that most students were having difficulty recollecting the laws and applying them in solving problems. After introducing the same lesson by using Hands-On-Activities, I noticed that all students were - at the very least - able to remember the Gas Laws. Some even tried to apply the concepts related to these, when they were promoted to X Grade. Above all, the entire class enjoyed learning.* Looking back at the various strategies that he had tried out, the teacher noted thus: *I personally found Hands on activities worked well because I was able to engage students with focus. At the same time they gained firsthand experience, which will help them remember what they learned, for a long time.*

Facilitator's observations

By the seventh month, the facilitator observed that the teacher had managed to turn around several inattentive students of his class through his changed methodology, and he had about 30% left to conquer. The facilitator probed the reasons for the teacher's altered approach, and received this response: *He said that when he reflected, he detected that he "was stuck." He had done the show-define-solve-problems routine to death, he realised.*

By the eighth month, the facilitator noted as below: *He shared with pleasure how he is the butt of envy of other teachers', as all his Class IX students have completed their Chemistry holiday homework! They haven't all done so in any other subject.* And after the classroom observation, she noted thus: *In his demonstration of the anomalous expansion of water [a difficult topic], he truly excelled himself. By freezing water in a plastic measuring cylinder, students noted that the volume had gone from 60 ml water to 67 ml ice! So they gathered actual evidence of the anomalous expansion of water.*

Teacher's shift in approach

The overall shift in approach was described by the teacher as below:

No.	Topic name	Previous method	Current method
1	Mole Concept	Lecture Method	Using different work sheets to define important terms and solve problems
2	Electrolysis	Lecture Method and using lab	Making voltaic cells. Using audio – visuals. Providing work sheets to practice chemical equations at anode and cathode.
3	Metallurgy	Lecture Method	Using audio - visuals to understand mining of aluminium.
			Giving group activities to understand the comparative study of metals and non - metals.
			Providing work sheets
4	Gas Laws	Lecture Method	Hands on activities - helps students understand the relationship between volume, temperature and pressure.
5	Introducing any topic	Lecture Method	Giving history behind the topic.

Table 2: Overall shift in teaching methods – some examples

Audio-visual tools: As the teacher began showing more videos to illustrate topics like metallurgy and electrolysis, he found that the interest level of his students spiked. *One of my weakest students in Class X was able to summarise the entire lesson after watching the videos in both topics. Previously, I used to first get the students to perform the electrolysis and then explain the concept to them. But now, by first showing the video, it helped him understand what happens at the anode and cathode in the* *electrolytic tank. Movement of ions is shown in these animations. So I found that videos are more helpful here, than in gas laws.*

Projects: By suggesting different projects, students' active involvement was garnered. They succeeded in making electrolytic cells that produced 3 volts of current, and this raised their confidence levels and gave them a sense of achievement. Students were also excited to make rockets, even though that project failed.

Students' feedback

At the end of the AR cycle, the teacher solicited feedback from students about their attitude to chemistry, through a written questionnaire. Comprising just three simple questions (what is your current feeling towards chemistry, what did you feel at the start of the academic year, give reasons if there has been any change), the questionnaire revealed that seven of ten students experienced a positive change in their attitude to chemistry. For want of space, only three are being quoted here: *"Initially, I found chemistry very tough and I was afraid. I would not be able to attempt even one question. But I did well because of Bhaiyya's support and teaching." "There is a big change* - *now I can understand easily by reading it myself and I can form chemical formulas." "I started liking chemistry when I did the experiments and when I noticed patterns."*

Observation and reflection by action researcher and facilitator

Reflection was now becoming more and more part of the teacher's practice, and he shared these with the facilitator whenever they met. Their discussions now veered around alignment of the learning objectives with the assessment framework. The teacher increasingly felt the need for such an alignment and also saw the importance of including skills and attitudes in his learning objectives, which he now realised had thus far been almost wholly content-driven. By the ninth month, the facilitator noted: *I noticed with pleasure that he has now adopted the pedagogic flow of demonstrate-and then-discover, rather than his earlier pedagogy of tell-and then-demonstrate. This is a level higher than demonstrate-and then-tell, which is what he had recently arrived at - in his own articulation of what I called his Aha moment. It is heart-warming to see him becoming less of a 'teller' and more of a 'facilitator'.* For example, the classroom observation notes of the facilitator go thus: *He had really thought through the pedagogy of Periodic Trends in Atomic Size. Using tennis balls and then configuring students to represent 11 electrons around a sodium nucleus, he drew from them the conclusion that as the force of attraction for outermost electrons increases, the atomic size decreases. As soon as he would posed the question to students about such a group trend (rather than tell it to them), they got it: that atomic size will increase down the group. Later, in the dining hall, I asked the most articulate boy whether he had had prior knowledge of the trends of atomic size. No, he told me. But he seemed to know, I insisted. "I deduced it," he admitted. So the teacher had engineered an AHA moment for several students today. The teacher pointed out to the class that if they 'got' this trend in atomic size cross a period and down a group in the periodic table, then they would have no problem understanding all other periodic trends.* The teacher noted in his tenth month that perhaps he had tended to skip certain points in the past because of not using the textbook adequately – something he had now begun to use far more. He also revisited one of his earlier assumptions - that the students knew all the basics - by now taking the trouble to check if they have the pre-requisite knowledge before embarking on a new lesson. He admitted that now, he thinks hard as to how to introduce hands-on activities into *each and every lesson* as he has found this to be a great way of engaging the challenging Class IX. He acknowledged the palpable enjoyment that then results.

The teacher recorded as follows: *Students have slowly started responding to me and I can see them even discussing the subject while walking around the campus. I found one student reading a book called* Disappearing Spoon *by Sam Keen, after which he came up with so many questions. Two formerly disinterested students started taking the initiative to learn the subject by the second term…and even requested me to help them out of class…which I did, in the evenings.*

Student performance

It may be noted that the most significant shift was in students' perceptible enjoyment in learning the subject, which is, of course a subjective indicator. A greater tendency to connect across chapters was observed by the teacher: e.g. while learning Metallurgy, they connected the extraction of aluminium to the application of electrolysis. Again, they linked Gas Laws to the solving of numerical problems based on chemical equations. A more measurable indicator of the impact of the teacher's AR would be the grades of the students in tests/exams. Mention is only being made here of one significant shift: viz., the performance in three Unit Tests on the concept that (in the teacher's own experience) *students usually find to be the most difficult*, viz. Mole Concept. It was noted that more than half the class showed a significant improvement in these tests (more than 20% increase in score).

Conclusion

Students who had shared that they were intimidated by chemistry now asked for a chemistry class if any other teacher was absent. Other teachers passing by the chemistry laboratory noted with awe the intense absorption with which students were engaged. The teacher acknowledged the role of AR in this entire journey as lending him a structure to work his way through. He noted that he has now become more conscious of planning, presentation and the work that he gives his students. This has had its reciprocal effect in that students now complete their worksheets on time and he receives no requests for extensions. If he forgets to give a worksheet, the students come and remind him to give them worksheets: a rarity *particularly from this class*, as admitted by other teachers! However, the teacher noted wisely as follows: *Despite all the strategies I may use, it is difficult to woo a student permanently to a subject. Their interests are fickle and they want newer and newer tricks to capture their attention. So my challenge remains to keep thinking of newer ways to keep them engaged and interested.*

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IN-SERVICE TEACHER ENHANCEMENT FOR IMPROVED SCIENCE CURRICULUM TRANSACTION: THE APPALACHIAN STS PROJECT

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A group of middle and high school teachers were involved in a one-year long professional development project that focused on the use of Science-Technology-Society (STS) pedagogical approach to the teaching and learning of science. The goal was to have teachers experience this approach and then design instructional units employing this approach for use in their own classes. The implementation of the STS pedagogy by participating teachers and its impact on student learning and teacher professional enhancement were investigated using a combination of quantitative and qualitative research methodologies. Results indicate that teachers improved in their ability to address several aspects of the vision of science education promoted by recent science education reform documents. They also indicate gains in student accomplishment, interest and effort in learning science.

Objectives and significance of the study

This paper reports the results of the impact of a one-year long professional development project on the enhancement of teachers' instructional approaches to accomplish the goals of scientific literacy and fulfill the vision of *National Science Education Standards* (*NSES*; National Research Council, 1996). Since the professional development project and the associated study were conducted prior to the advent of *A Framework for K-12 Science Education* (National Research Council, 2012; referred to as *Framework* henceforth), the paper will also make connections to how this professional development project connects with the *Framework* and how the model used in this project is useful even in the context of the *Framework*. This connection to the *Framework* is important because the *Framework* stimulated and served as a guide for the development of the *Next Generation Science Standards* (*NGSS*; Achieve, Inc., 2013) in the USA, which are either directly being adopted by individual states or are being used by the states as a guide for the revision of their own science standards.

Since the project involved secondary science teachers in the US state of North Carolina, the project also took into account the North Carolina Standard Course of Study (*NCSCOS;* http://www.dpi.state.nc.us/curriculum/science/). The *NCSCOS* is the state mandated curriculum followed in all public schools across the state of North Carolina in the USA. The science "strands" in the *NCSCOS* include: Science as Inquiry; Science in Historical Perspectives; Science in Personal and Social Perspectives; and Science and Technology. Students are tested statewide in "end-of-course" (high school) or "end-of-grade" (middle/junior high school) tests on the *NCSCOS*. Most science teachers tend to focus on the teaching and learning of 'content' topics prescribed in the *NCSCOS* so narrowly that the "strands" (understanding the nature of science, understanding science as a process of inquiry, understanding the relationships between science and technology, and understanding the personal and social implications of science) remain largely unaddressed in school science instruction. The Appalachian STS project involved teachers in experiencing and then trying the Science-Technology-Society (STS) pedagogical approach in their classes to address the science "strands" of the *NCSCOS* in a 'seamless' manner while addressing the 'content' topics of the curriculum.

The STS approach (Figure 1), defined by the National Science Teachers Association (NSTA, 1990 – 91) as *the teaching and learning of science and technology in the context of human experiences,* has been found effective in addressing these "strands" (Dass, 1999). The study being presented in this paper examined the impact of a one-year long, STS-based professional development project on the effectiveness with which participants addressed the *NCSCOS* science "strands" in their classes. The objective of the study was to investigate the extent to which STS pedagogy enables teachers to address these "strands" more effectively while teaching the prescribed 'content' of science, as well as to investigate factors that influence the use of STS pedagogy by the participating teachers.

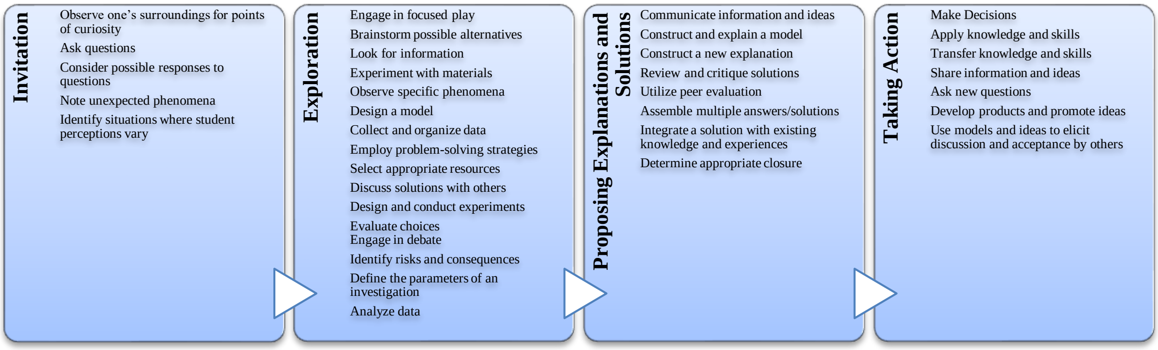

Figure 1: The STS pedagogical approach

Studies exploring the impact of professional development projects aimed at enhancing teachers' ability to address components of scientific literacy are significant as the focus of science instruction world-wide has been shifting from rote learning of the so called 'content' of science to developing a sound understanding of the essential features of science and its role in personal and social life of modern human society (e.g. National Research Council, 1996; Millar & Osborne, 1998). The *Framework* and the *NGSS* identify three "dimensions" of science that ought to be addressed in tandem during science instruction. These "dimensions" include: Crosscutting Concepts; Disciplinary Core Ideas; and Scientific and Engineering Practices (referred to as *Practices* henceforth). The *Practices* dimension closely matches some of the components identified in the *NCSCOS* "strands". Thus, professional development in the use of the STS pedagogy can be useful in accomplishing the three-dimensional science instruction proposed and promoted by the *Framework* and the *NGSS*. Given the shift in the importance of seamlessly incorporating scientific inquiry (*NSES* and *NCSCOS*) or scientific practices (*Framework* and *NGSS*) in science instruction, there is a need for new learning and professional development opportunities for in-service teachers to enable them to accomplish these shifts in their instructional practice. Studies investigating the impact of such opportunities play a significant role in assessing the effectiveness of the professional development programs in enabling teachers to accomplish the new curricular goals of scientific literacy.

Theoretical framework

The National Science Education Standards (*NSES*) were predicated, among other things, on the following recognition: *"Everyone needs to use scientific information to make choices that arise every day. Everyone needs to be able to engage intelligently in public discourse and debate about important issues that involve science and technology."* (National Research Council, 1996, p.1). This same recognition continued to pervade the vision for K-12 science education in the development of the *Framework*, as evident in PART I of the *Framework* (National Research Council, 2012, pp. 5–38).

Two of the four 'goals for school science' that underlie the *NSES*, focus on the use of scientific knowledge and skills in personal decision-making and public discourses (National Research Council, 1996, p.13). These goals expand the purposes of science education in the 21st century. They call for a type of science education that equips students with more than 'head knowledge' of the so-called scientific facts. The same vision guided the development of the *Framework*, in which the recognition of the three dimensions of science and a three-dimensional approach to science instruction is seen as important in helping students both understand and use science in their daily lives. Individual state science curriculum standards, such as the *NCSCOS*, in the USA, often tend to reflect the goals, vision, and spirit of the *NSES* and the *Framework*, thus intending to promote scientific literacy at the state level. However, the vision inherent in the *NSES* and the *Framework* immediately raises the question of how capable our science teachers are to accomplish these purposes of science education in their classes. In order to accomplish the vision of the *NSES* and the *Framework*, substantial changes are required in the way science has traditionally been taught and that means substantial changes in the way professional development for in-service science teachers is designed. Thus, reforming professional development of in-service science teachers becomes a prerequisite for accomplishing the scientific literacy vision inherent in the *NSES* and the *Framework*.

Focusing on the teaching and learning of science in the context of human experiences, STS emerged as a pedagogical approach showing the promise of accomplishing the vision of science education promoted by a number of reform documents published internationally towards the end of the 20th century and into the 21st century thus far. Based on the evidence accumulated during the final decades of the 20th century to demonstrate the effectiveness of STS as a pedagogical approach (Dass, 1999), it is argued that enabling science teachers to use STS instructional approaches in their classes can lead to the desired science education reform and fulfill the vision of *NSES* and the *Framework*. This, in turn, implies that using STS approaches in professional development projects is desirable if professional development is expected to advance these visions of reform.

The ensuing description highlights ways in which secondary school science teachers used STS instructional approaches to address the science "strands" of *NCSCOS* in their classes as a result of participating in the Appalachian STS Project of professional development. Also reported is an analysis of the impact of this STS-based professional development on student learning and teachers' own professional development.

The structure of the Appalachian STS project

Emulating the STS-based professional development model of the Iowa Chautauqua Program (ICP; Dass & Yager, 2009), the Appalachian STS Project engaged participating teachers in the following activities.

- *Two-week long Summer Institute:* Teachers experienced the STS pedagogy as if they were students. Then they designed grade-specific STS instructional modules addressing state science standards for use in their own classes. Figure 2 lists some of the modules created and implemented by participating teachers.
- *Fall Classroom Implementation* of STS instructional modules developed by the teachers during the summer institute.
- *Fall Weekend Workshop* focusing on classroom implementation results and preparing for state science teachers conference presentations.
- *Presentations* at North Carolina Science Teachers Association Annual Conference focusing on results of classroom implementation of the STS pedagogy.
- *Classroom Action Research Projects* throughout the academic year focusing primarily on comparing student achievement between STS modules and traditional units on the same topics.
- *Spring Weekend Workshop* focusing on the results of the action research projects.
- *Interim Electronic Communication* throughout the duration of the project.

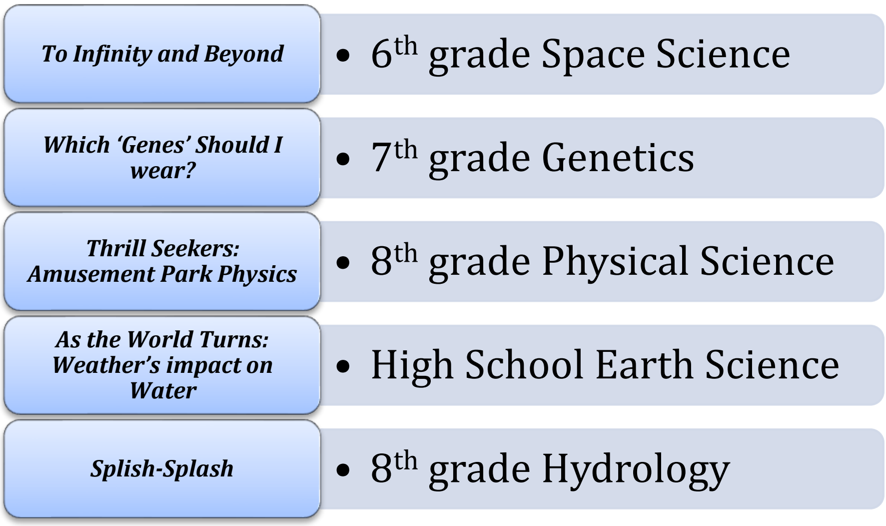

Figure 2: Sample STS modules created by participating teachers

Research design and procedures

Participants

There were 17 initial participants in the project but only 12 completed the full year program. These program completers represented 11 schools in the northwestern region of North Carolina and represented grades 4-9. Three of the program completers had masters degrees and nine had a bachelors degree. Two of the program completers were males and the other 10 were females. Five of the program completers (each from a different school) gave the follow-up interviews during the year after program completion. Of these five, 3 were middle school teachers and 2 high school teachers.

Data collection

This study combined elements of both quantitative and qualitative research methodologies, including administration of a survey instrument (“Perspectives on Teaching Science”; Blunck, 1993) to project participants, observations of their classroom instruction, and formal individual interviews with them regarding their perspectives on the use of the STS approach in addressing the NCSCOS “strands” of science. The survey instrument was administered as a pre- and post-test at the beginning and end of the one-year long project. Classroom observations and interviews were conducted during the academic year following the completion of the project period to gather information regarding the teachers’ continued use of the STS pedagogy and its impact on both students and teachers themselves.

Data analysis

The quantitative survey instrument data were analyzed using the following statistical procedures:

1. *Paired samples T-test* of individual items on the questionnaire ($\alpha = 0.1$);
2. *Reliability Analysis* of grouped items on the questionnaire into FOUR specific Professional Development Areas (Alpha Scale; PDAs: Confidence to teach science; Concerns with regard to teaching science; Comfort level in dealing with controversial topics in science, differing student opinions in the classroom, etc.; and Ability to collaborate and communicate with colleagues and community members).
3. *Paired Samples T-test* of the four PDAs (based on item groups; $\alpha = 0.1$); and
4. *Effect Size analysis* of those individual items and PDAs whose T-test results were significant at 0.1 α value.

The qualitative data from classroom observations and individual teacher interviews were analyzed using the “constant comparative” method (Bogdan & Biklen, 1992). The observations focused on teachers’ use of STS approaches and ways in which they addressed the science “strands” of the *NCSCOS* in their lessons. Interviews focused on the following key questions:

- In what ways has the STS instructional approach helped you in addressing the science STRANDS of *NCSCOS*?

- In what ways has your use of the STS instructional approach impacted student learning in your classes?
- What impact has the Appalachian STS project had on your own professional development as a science teacher?

The results of the quantitative and qualitative data analysis were compared to triangulate findings and reach reasonable conclusions.

Findings

The statistical analyses of quantitative data indicate that participation in this professional development project enhanced teachers in the following three of the four PDAs: Confidence to teach science; comfort level in dealing with controversial topics in science, differing student opinions in the classroom, etc.; and ability to collaborate and communicate with colleagues and community members. The Paired Samples T-test of the four PDAs and Effect Size analysis of the PDAs indicating significant positive change are presented in Tables 1 and 2 respectively.

PDA	**Paired Differences**			**df**	**t**	**Significance** (2-tailed, $\alpha = 0.1$)
	Mean	**Std. Dev.**	**Std. Error Mean**			
Teaching confidence	-0.650	1.1927	0.3596	10	-1.808	0.101
Teaching concerns	-0.0909	0.7183	0.2166	10	-0.420	0.684
Comfort level	-0.338	0.5431	0.1638	10	-2.062	0.066
Collaboration & communication	-0.286	0.4472	0.1349	10	-2.119	0.060

Table 1: Paired Samples T-test of the four PDAs

PDA	**Paired Differences**		**Effect Size** (Mean/Std. Dev.)	**Percentile Change**
	Mean	**Std. Dev.**		
Teaching confidence	-0.650	1.1927	0.54	70
Comfort level	-0.338	0.5431	0.62	73
Collaboration & communication	-0.286	0.4472	0.64	74

Table 2: Effect Size analysis of PDAs with statistically significant positive change

Analyses of the qualitative data revealed that participating teachers became more confident about addressing several of the science “strands” in the NCSCOS. They also indicate that the STS instructional approach provided means of addressing these "strands" seamlessly within the content modules rather than to be treated separately. Thus, project participants have been able to overcome the time issue that typically prevents most teachers from addressing these "strands". The results of the question-wise analysis of interview data are presented below.

Question 1

Teachers' ability to implement an inquiry approach to science learning and their use of technology in doing so, as well as pointing out the connections between science and technology, improved through the use of STS pedagogy. They became better able to bring out the societal and personal connections of science, thus enabling students to better understand and appreciate the real-life relevance of classroom science learning. The following comments from participating teachers are representative of the impact of the STS pedagogy on teachers' ability to address the "strands" of science in NCSCOS.

- *Two strands stand out above the others, Nature of Science and Science as Inquiry… STS helped me better realize in my own life how science is about actively seeking and being involved in the process of learning… I have used knowledge gained from STS to create and direct my students into inquiry based activities… Their learning has lasted longer than if I told them the answers.*
- *One of the biggest is the inquiry because I can come in and ask a question and they want to take it a little bit farther… it gets them thinking. They think outside of the box.*
- *Some students decided to test water in the school… they tested in four different areas… They went to the water treatment plant and found out all about that… They have presented their findings through PowerPoint to several groups.*

Question 2

When considering the impact of STS pedagogy on student learning, teachers reported growth/improvement in the following areas.

- Improvement in attitudes toward science and science learning.
- Greater effort at learning science, including outside the classroom.
- Better retention of material learned.
- Noticeable improvement in test scores.
- More inquiring minds—better quality and quantity of questions raised and pursued by students.

The following teacher comments are representative of the impact on student learning.

- *A lot of students who have had me for biology will also take forensic science because I use a lot of inquiry-based activities in that class and that's the reason they tell me they sign up for the forensics class… They feel that they have not always received that in the other science classes so that encourages me to use it (STS) more and it shows me that students actually enjoy it.*
- *Students have a greater desire to learn more about the science that we are looking at. I see more thoughtful questions from the kids, trying to look a little deeper at a topic… I've gotten parent responses telling me that their children are enjoying the science classes where they have not enjoyed classes in the past.*

- *Prior to last year, we were last in the county, but last year we were pushing up there closer to the, not to the top, but at least in the middle, so we had improved quite a bit (in terms of performance on the State End-of-Course exams)*

Question 3

With regard to the impact on teachers' own professional development, participants reported enhancements in the following areas.

- Improved communication between colleagues.
- Greater leadership exercised by participants.
- Greater enthusiasm about science teaching.
- Improved perceptions of learners and the learning process.
- Better management of the learning process.
- Better use of human resources in school and the outside community.
- Decreased reliance on textbook and worksheets and increased use of inquiry-oriented teaching and learning.

The following comments represent teachers' perceptions of how the Appalachian STS Project influenced their own professional learning and development.

- *I think it has built my confidence to talk to other teachers about it… I have done some workshops with people in my department… I have also created two, three lab manuals that have a lot of inquiry-based STS type activities in them to encourage other teachers to use them and actually mailed them out to other counties.*
- *It has made a difference in my teaching as far as how I look at the kids and how I look at them as students and learners… I am excited about science and I am excited about learning new parts to science and I want to share everything I know about science… I am using this in my national board (examination) as one of my accomplishments. I talk to all my colleagues and share whatever I've learned… I go to all kinds of conventions.*
- *I have grown in my understanding of the curriculum requirements (in terms of the 'strands')… My management skills have grown some and now I can manage kids being at different places in the classroom working… I have been able to see where I needed to change and move away from the textbook and more toward the inquiry…*

Collectively, the analyses of all quantitative and qualitative data indicate that the STS instructional approach promoted in the project helped participating teachers to address the science "strands" more effectively and more thoroughly. The results also indicate that participating teachers grew significantly in ways that make them more capable of addressing the science literacy components embodied in the science "strands". All of the participating teachers presented their efforts and results (of implementing the STS pedagogy) at the state level science teachers' conference and several of them published the results of their classroom action research projects in peer-reviewed teacher practitioner journals. Thus, it can be claimed that the Appalachian STS project was successful in positively influencing 12 teachers in the northwestern region of North Carolina for promoting the kind of scientific literacy envisioned in the *NSES*. It is further hoped that with this professional development, these 12 teachers were poised to better implement the vision of the *Framework* in their classes when it was published in 2012.

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EXPERIENCES AND LEARNING FROM PARTICIPATORY ACTION RESEARCH WITH A LOCAL SCHOOL

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We report on an intervention in the Environmental Studies (EVS) curriculum of a lower-income elementary school. The intervention was carried out through collaboration between members of our R&D Centre in science education and teachers of the elementary school. The paper overviews the first two years of this ongoing long-term collaborative association. We consider the motivations and driving forces behind the collaboration and also discuss and reflect on our learning so far – the small successes and the continuing hurdles that challenge this association as well its joint objectives.

Introduction

For researchers and developers in science education, direct and continual engagement with students and teachers in science classrooms can provide valuable learning and insights. This particular project is planned as a longitudinal engagement with students as they progress from grades 3 through 10. The school and its teachers, our partners in this project, seek to practice constructivist methods and student-centred learning in their classrooms, which is the mandate of the State Curriculum Framework. They are interested to discuss, plan, try out and evaluate feasibility of constructivism-based teaching strategies to help address challenges in science teaching, mostly within the existing academic settings. It was with these shared aims that a collaborative action research project was planned.

Motivation

This participatory collaborative action research project was initiated by the R&D Centre as a result of a self-review which brought out the need for fostering close connections between research, resource development, outreach and advocacy (HBCSE, 2014, p.96). The review recommended continuing engagement with 1-2 schools and colleges which would keep R&D efforts informed by the practice of teaching. Building and nurturing linkages with school systems would provide avenues to examine our ideas; further, such relationships could offer opportunities to seed science education capacity in schools (HBCSE, 2014, pp. 101-102).

Collaboration of the R&D Centre with this particular school came about on the background of occasional contacts in previous decades in which students and teachers from the school had participated in workshops or in testing of materials or consented to serve as samples in research projects. Publications of the R&D Centre were used by the teachers as resource materials. As a result of familiarity and mutual regard, the principal and teachers of the school readily agreed to participate in the project. The participatory collaborative nature of the project required the nurturing of an equal partnership between teachers and researchers/developers. Our efforts and learning in this regard are described below.

Participatory action research

Research involving schools, or teachers, is routinely carried out by researchers who are total outsiders to the school and/or community of teachers. Often, relevant communities are not even consulted for inputs that could inform cost-effective research investigations. Even if a concerned community does get some say, they hardly possess any control on the subject matter or agenda governing the research (Campos, 2005). We envisaged conducting this particular project differently from conventional research. The core team chose to adopt the participatory action research (PAR) approach and work "with" rather than "on" school teachers (McIntyre, 2008; Weingarten 2012). The PAR approach, based on a process of collective self-inquiry, is recognized to be empowering, democratic and driven by the intent to develop knowledge and action that is relevant to all participants (Gayford, 2003; McIntyre, 2008).

Marshall and Rossman (2006) termed PAR as a dynamic educative process, an approach to social investigation, and an approach to take action to address a problem or to engage in sociopolitical action. Moreover, as in all kinds of action research, PAR involves a cyclic process of research, reflection, and action. In PAR, the emphasis is on research for change and development of communities rather than for its own sake, i.e., importance is given to knowledge that is useful in improving lives rather than for the interest of academic research and being under the control of academics (Cohen, Manion & Morrison, 2011). PAR is a research methodology which enables researchers to work in partnership with communities in a manner that leads to action for change. In this project, we proposed to work together with participation of all stakeholders – the school authorities, teachers, students' parents, students and researchers – to address mutually identified problem areas in elementary science education. The discussion below focuses on the initial processes in development of this project, the approach adopted to implement collaborative participation and action and our continual learning from the experience.

The project: getting started

The project began in mid 2014 and a team from the Centre met the partners from the school numerous times either at the Centre or sometimes in the school where due to lack of space fewer meetings were held. During the first meeting, the school team was requested to respond to a questionnaire, which sought their views on the challenges they faced in science teaching, their teaching strategies, students' classroom participation, science content, as well as the school's expectations from the collaboration. Some responses from the teachers are described in the section "experiences and learning".

Further, we obtained the school's consent to observe some classroom sessions conducted by the teachers. These class observations were aimed at obtaining first hand information about how a new topic is introduced to students, teachers' questions to students, frequency and nature of students' questions and talk or discussions during the formal delivery of science content. It was anticipated that findings from our observations of classroom teaching would inform the approach and strategy for this project. Additionally, the team also obtained permission to conduct some science sessions for grade 3 students. We thus hoped to acquire a direct feel and understanding of the school context and environment, in addition to the nature of science content and its delivery to young students in classroom.

Initial interactions with the school, described above, led to the idea of conducting a month-long summer vacation camp (May 2015) for the students entering grade 3. The proposal, which was welcomed by the school, gave us an opportunity to interact with young children (7-8 years) and try out different teaching strategies to support science learning, language development and creativity in students. We explored methods that would create interest and engage children, stimulate dialogue, asking of questions, sharing of views with peers and instructors etc. During the camp, students participated in planning and conducting science experiments, creating design patterns, animated stories, drew to express their thoughts/understanding, were engaged in critical reading, story writing and narration, model making, etc. These interactions with the children helped develop a rapport and understanding of their learning needs. The number of attending students was however quite small – only 10-15 – due to the fact that most students went away to their villages during vacation. (On the participant students' interest and request another camp, for grade 4, was organized during summer vacation of the following academic year too).

Approach

The actual classroom sessions on EVS teaching and learning started in the academic year commencing June 2015. The school has four sections for a total of more than 200 students studying in grade 3. The school designated one of the four grade 3 sections, consisting of 53 students, to the project. In grade 3, one class teacher (CT) deals with teaching of all academic subjects; namely, language, math and environmental studies (science). In the first year, this particular CT was the person with whom Centre representatives interacted. Responsibility for classroom delivery of the twenty six chapters in the EVS textbook was distributed among the Centre's team members. At least one week prior to the classroom sessions scheduled for a chapter, the concerned member would seek and meet the CT. These meetings offered space and time to share perspectives and ideas, discuss chapter content and its contextualization, deliberate on teaching strategies (keeping direct instruction to the minimum), and come up with a collaboratively designed lesson plan and activities for the chapter. The meeting was an opportunity for the CT to share any concerns related to teaching, teaching-learning material, concept clarifications, etc. One week (total of six sessions of 45 minutes each) was assigned to the teaching of each chapter in the text book. Every week, four of these science sessions were led by a team member from the Centre and two were conducted by the CT, though the CT and the Centre's members were present for all sessions, which were documented. Thus, in the initial stages, the burden of teaching was largely on us.

In the second year, our collaborative work on school science teaching advanced to the next grade. As in the previous year, the school designated one of the four sections of grade 4 to the project. A majority of the students in this section belonged to the batch we had interacted with in the previous academic year. In this grade too, there is one CT who deals with the teaching of all academic subjects. In the second year of the project, the school team included CTs of all four sections of grade 4. The responsibility of designing the lesson plan and activities for the 28 chapters in the EVS textbook of grade 4 was distributed among the four CTs. (This was different from our first year interaction with grade 3, where only one CT was involved in planning for all chapters. It was expected that this CT would share her experiences and material from the project with CTs of the other three sections of grade 3, though the implementation mostly took place in the selected section). This change was introduced in response to feedback obtained from students' parents and communicated to us through the head mistress (see below). Inclusion of all grade 4 teachers in the PAR aimed to facilitate simultaneous implementation of the designed lesson plan and activities in all the four sections of grade 4. As in the first year, the CT and Centre representative responsible for leading the work of planning and preparation for a chapter would meet to discuss and finalize the lesson plan and classroom sessions, at least one week prior to the chapter's schedule. This included deciding on activities to be conducted or demonstrated in class, content and design of worksheets, selection of desired audio-visual material etc. These discussions were shared with the entire PAR team (all 4 CTs and Centre members) during monthly meetings. Feedback and suggestions thus obtained were considered during finalization of specific sessions on the chapters. Another change in the second year was that the CTs' lead in conducting classroom sessions was increased from two to five sessions per week, while the Centre members now led only one classroom session per week. We however continued to collaboratively contribute to the design, planning and observation of science teaching in the designated class. The increase in number of sessions to be conducted by the CT was anticipated to increase the teachers' involvement and ownership of strategies being attempted for science teaching. With involvement of all the four teachers from grade 4, the collaborative effort was extended to include all the students of grade 4 (approx. 200 students versus 53 earlier). This was possible because all lesson plans, activities, worksheets etc prepared for the designated section of grade 4 were immediately shared with the other three divisions for simultaneous use.

One strategy suggested by us and adapted by the school included the design and use of worksheets to support students' learning. This suggestion aimed to address concerns about involving every single child in the learning-teaching process, as well as to provide students with opportunities for language practice and development. Use of worksheets can be a useful strategy to identify and address student misconceptions and facilitate learning for understanding (Griffin and Symington, 1997). Worksheets used in this project were mostly designed by Centre members with inputs or modifications suggested by the teachers. We drew on previous research that suggests that simplifying language of textbooks can improve teacher-pupil interaction in classrooms (Kulkarni & Gambhir, 1981). Research in science education has studied how students' learning follows from doing experiments or watching demonstrations (NCF, 2005). Experiences of team members from the Centre in developing simple low-cost experiments helped bring experiments and demonstrations to the classroom sessions at our partner school. A good pedagogy must essentially be a judicious mix of approaches, with the inquiry approach being one of them. Some variations from the conventional instructional mode for teaching, introduced through the collaborative project, included model making, intentional creation of an experience or situation, role play, interviewing, visit to community utilities, etc. These activities were collaboratively planned by us and implemented by teachers who received facilitative support from the members of the Centre. In addition to documentation of the ongoing project, it is envisaged that the data will also support the meta-objective of developing a model for participatory action research that involves teachers and researchers working collaboratively with inputs from parents and students.

Sources of data

Data for this project consisted of written records as well as video and audio recordings. The written data included minutes of all PAR meetings among the Centre participants, joint meetings between teachers and Centre participants, questionnaire responses and feedback provided by teachers, notes and reflections from lesson-planning related discussions and interactions, actual lesson plans and documented observations of classroom delivery sessions. Besides there were worksheets developed and students' work on these sheets was also a source of data. While a great deal of data has been generated, we have so far analyzed only a limited amount of the data.

Experiences/ Learnings

We share below some thoughts based on the school teachers' response to our questionnaires, preliminary analyses of our documentations of the initial class observations (prior to commencement of the collaborative classroom sessions at the school) and the EVS sessions conducted collaboratively in grades 3 and 4 and the summer camp sessions. Our initial interactions and classroom observations and teachers' comments suggest the difficulties in classroom teaching-learning (Tables 1 & 2).

Teachers' responses to questionnaires

When the teachers were asked about the difficulties faced in science teaching, their responses related to concerns regarding students' ability to understand textbook language. They thought the formal science language, vocabulary and terminology to be too complex for their students who mostly speak different dialects of the state language. The query about the kind of questions students ask in class told us that students ask questions (usually only when asked to do so) to satisfy their random curiosities, like, 'Why does kerosene smell?' The projects students worked on were usually in the nature of collecting pictures on given topics – animals, birds, medicinal plants, etc. Sometimes there were weekly themes with related activities, e.g. nutrition. Teachers also mentioned writing essays on various topics (eg. cleanliness) as project work. In response to our question about their own expectations from our Centre through this project, the teachers mentioned being interested in workshops on different pedagogical strategies, and designing of activities for science teaching and learning. The teachers also mentioned that they would welcome opportunities for meetings with researchers at the Centre to discuss and share ideas about science content and its teaching.

Our learning from classroom observations

We found that the teachers were interested in use of audio-visual resources, largely PowerPoint presentations and videos or pictures, to support their teaching. Our role, with the advantage of better resource access, was in the selection of relevant pictures that were clear to view and understand. Also, such pictures could be colourful and attractive so as to draw students' attention and interest to the subject being depicted. Later in grade 4, we found that teachers too obtained appropriate and attractive illustrations. Language related difficulties were noticed among students in most classes we observed. For example, some students found it difficult to write and read '*jodhakshare*', i.e. words that combine 2 or more words; for example, '*shwasochawaas*' was referring to breathing. This problem was addressed by the use of simpler words, making it easier for students to understand the content. We also noted initially that students rarely had the opportunity to ask questions. Encouraging students to ask questions is necessary to motivate and nurture their curiosity. Direct involvement of students in classroom proceedings and learning seemed to be initially missing. This was addressed, for example, by inviting students to participate in experiments or demonstrations being shown in class. Also, there were more explicit attempts to connect science concepts being taught in class with instances from routine day to day life. We observed that students did talk and respond whenever opportunities were provided. Teachers need to create or enable experiences, situations or activities to motivate students to speak. Tables 1 and 2 depict the difficulties faced by teachers and students as derived from the questionnaire responses and from our observations.

Feedback from the school

Through observing the CT, we came to appreciate her exceptional skills at keeping the students engaged – with a fund of stories, songs, drama and action. On the other hand, the mid-term (September 2015) meeting highlighted the drawbacks in our teaching skills. At this review meeting, we faced much criticism from the CT. We realized that by taking on the task of teaching we had subjected ourselves to judgment by the CT regarding our teaching skills. It may have distracted her (and us too, perhaps) from what we meant to do – demonstrate the implementation of various teaching strategies. Our documented observations substantiated the teachers' claims about our struggles – though mostly in class management.

In the mid-term review meeting the CT's comments indicated that she considered direct mention of each and every part of the text-book content, in classroom sessions, essential. However, in the year-end meeting the teacher showed more openness and even praised methods that didn't directly involve stating every single bit of text-book content in the classroom. Of course, whether such lesson sessions have still conveyed to students the content remains to be evaluated. Initially the CT seemed unhappy with our methods of eliciting students' responses and participation by asking questions. The teacher felt that students should not be asked too many questions, probably as it takes times and disrupts the discipline and flow. This stance appeared to change by the end of the academic year. The teacher shared that she had learnt (from us) how to get students engaged in learning by asking them questions. This is one of the instances where the CT directly acknowledged having gained from the collaboration.

Number & diversity of students in class	• Average number of students in each class is more than fifty- rendering class management a challenge. Some students did not pay attention in class and some at the back of the class were fidgety and disturbing others. • Students in each class varied with respect to cultural, social, parents' education and economic backgrounds.
Subject knowledge & teaching for understanding	• Teachers find it difficult to understand some science concepts. They may be limited by their own or students' language and struggle to frame/explain concepts. • Teachers are expected to provide students with variety of examples to complement limited material in text books. At times teachers may find it difficult to go beyond the textbook and link content to student contexts and day-to-day life situations. • Not all teachers can create conditions that facilitate questioning among students.

Activities & evaluation	• Teachers are unable to pay attention to individual students as they are bound by the need to complete the syllabus on time. This may also be the reason for not conducting any activities in class. Another hurdle related to this is the fear of disrupting class discipline. • Teachers rarely receive the support, guidance and help they need from the school principals, school management committee, colleagues, etc. • The time for completing desired evaluations/ assessments may also be limited. Preparing evaluations and assessing students is also challenging. Emphasis on scoring and teacher accountability may lead to 'teach to test'.
Miscellaneous	• Teachers are expected to perform tasks unrelated to education, for example, collect information for government during census and elections. These tasks take up a lot of time and energy that could be used for educational purposes.

Table 1: Difficulties faced by teachers in science teaching at grade 3

Language difficulties	• Students seem to connect with or understand science content that is being discussed in class but may not be able to express the same due to difficulties with language. • Textbook language may not be the students' mother tongue or is quite distant from the spoken language making it difficult for students to comprehend. • In grade 3 students are often struggling to learn to write.
Teachers' perspective of students	• Teachers may pay attention to certain students in a class and ignore others, resulting in de-motivation. • While corporal punishment is illegal, teachers may still use it and/or harsh language resulting in young students not being able to connect with teachers or the subject being taught.
Student participation and involvement	• The opportunity for students to participate actively and for student voices to be heard in class is rare. Dialogue is neither encouraged nor are students allowed to question or raise doubts. • Student questions often result in unsatisfactory answers or may be ignored. This situation may result in a loss of interest and boredom in class. It also results in an authoritarian climate that induces fear and lack of openness.

Table 2: Difficulties faced by students in learning EVS at grade 3

At the end of the academic year, though less, there still seemed to be some resistance to use of worksheets in the classroom. The CT felt that all children might not be engaged in writing (on the other hand, apparently, the number of students engaged through worksheets seemed more than when responses were elicited via verbal discussions alone). The other issue was that completing worksheets took up more of the class time – but again written expression and language skills had been earlier identified as areas of focus for this batch of students. We need to find a way to show that worksheets have helped (if at all) in improvement of language skills among students.

In the project review meeting at the end of the first year of the project, the head mistress (HM) provided positive inputs regarding the effectiveness of the project and its impact on students' participation in class. The HM shared that parents of students from sections (grade 3) other than the one designated for the project had heard about the happenings in the collaborative project and expressed the desire that their children's classes also be a part of the PAR project. It appeared that parents anticipated some benefits to their children's' learning from the project and wished the same opportunity for their children too. The HM supported the views of students' parents. She suggested that all four sections (of grade 4) participate in the second year (see approach) and benefit directly from the resource materials and teaching-learning strategies developed as a part of the PAR project. She conveyed her belief that the PAR team can help bring something new and useful to enhance existing teaching methods in the school. It was suggested that the Centre members and teachers meet after every classroom session and exchange feedback/suggestions to add value to what was being done in the ongoing sessions. The HM also made observations about some (newly developed) desirable characteristics in students of the section assigned to PAR project in comparison to students in other sections. The HM shared that on interacting with students of all four sections, she found that the section designated to the project seemed to be (i) quick in responding to questions (ii) actively participating during class room interactions /discussions with the teachers (iii) speaking spontaneously to share their thoughts and ideas and (iv) asking questions with some understanding and not just for seeking attention. This may be considered an improvement over the September 2015 comments where the only mention of student improvement by the CT indicated students having become bold.

Reflections

This participatory action research project is different from our earlier research projects and our understanding of research projects. Here, each stakeholder is expected to contribute through her/his field of expertise. Thus, while members from the Centre could provide research and development based inputs, the school teachers contributed through their experiential understanding of classroom teaching in formal schooling. However, in practice we perhaps had to keep reminding ourselves that this is a participatory project. Especially when we decided to take up the role of class-room teaching, which was not our strength. In fact, in the summer-camp itself some of us realized our limitations – of lack of teaching experience, especially in the local language, or of toning down our teaching to children as young as 8-9 years. These limitations got magnified in the actual classroom which had four times as many students as the summer camp. However, the experience was valuable in that it impressed on us the complexity of teaching science to primary school students, in vernacular language. The fact that different individuals of the Centre's team were responsible for planning and implementation of classroom delivery of different textbook chapters demonstrated varied perspectives and approaches to science teaching. That we realize our limitations and strengths is important and this understanding helped us become more realistic during the second year of the project, introducing some changes in our roles during classroom delivery. Active involvement of teachers from all four sections of grade 4 along with the head mistress, in the second year of the project at every step of planning, designing and implementation of classroom sessions made the project truly participatory in nature.

Conclusions

Based on more than two years of interaction with students and teachers at the school, some basic learnings gained from the project are stated as below:

a) Design and use of classroom activities have potential to encourage students' participation, probe their existing understanding and prompt them to ask questions.

b) Worksheets that consist of few questions, give space for drawing, seek brief answers, may be more effective in supporting desired learning.

c) Activities involving some simple games, use of flash cards, puzzles, blackboard work involving drawings and flowcharts, etc. support learning by creating interest among students. They also provide opportunities for students to think, reflect and question. Equally important, they help break the monotony of a transmission based classroom.

d) The teachers indicated that they learned some newer pedagogic strategies by actually getting to practice them. They mentioned having started to think outside the textbook content to make classroom science relevant to students.

For this project, we also had the added objective of developing materials/modules/ handbooks that can be resources for future use by teachers. This attempt is ongoing, with the work on compiling the worksheets and re-framing them. At this stage in the project, it is difficult to state distinct ways in which students may have benefited from the project. During interactions, some teachers commented that they feel that this batch of students will be quick to acquire the ability to 'think scientifically'. We report concerns and challenges in seeking data that would permit comparison of students who are a part of this project with those who are not. Comparisons are a sensitive issue. Our focus is more on developing a healthy and respectful relationship with the school. As was aptly said by one of the teachers – *'the children are growing now, they are getting mature, we will see the difference in the coming years'*. Implicit in her statement is the confidence that the ongoing changes in classroom teaching of science will impact students in a positive way. For now, based on our classroom observations, we can state that the number of students asking questions, participating in discussions and answering questions has gone up. Some children who used to quietly watch seem to be actively participating. But, these are yet only informal evaluations. One question that needs to be asked is - since our main role is in lesson/activity planning and observations of the same, can we structure these so as to obtain the requisite research data in an implicit manner?

Acknowledgements

We thank the head mistress and teachers at our partner school for making this collaborative work possible and acknowledge all members of the SSRD team; Riyazuddin Sheikh, Meena Kharatmal, Karun Hambir, Susneha Ayare, Varsha Pawar, Devashree Prabhu, Disha Gupta, Trupti Adangale, Adithi Muralidhar, Pooja Sharma, Namrata Kadam, Ashwini Dhanvijay, Rohini Karandikar, Rupali Shinde and Arundhati Dolas who are a part of this project. We thank the short-term interns and visitors

(Savita Mali, Rihana Mulani, Bhawna Gera, Suraj Jaipurkar and Shrijita Sengupta) who took interest and worked briefly on this project. Most importantly, we are grateful to the wonderfully enthusiastic students at the school who have been our constant motivation.

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ZONE OF PROXIMAL DEVELOPMENT IN THE ERA OF CONNECTED COMPUTERS

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The zone of proximal development (ZPD) could be a fruitful framework for understanding processes that enable learning in a collaborative environment. How can one create a platform with connected computers which would allow the learners to create a ZPD by design? We discuss design requirements for such a platform and we present two examples to substantiate our arguments. The examples considered are learning of arithmetic and learning to type using a Indic keyboard. We found that the natural desire of the learners to share and gain knowledge with peers could become an inherent source of sustainable interactions which facilitate learning. The learner's role shifts dynamically between being a mentor and a mentee. The digitized interactions offer the platform as a 'player' for both synchronous and asynchronous modes of accessing the otherwise fluid social interactions. This facilitates the creation of a motivating context for engagement (both online and offline), which is nothing but a ZPD, that is essential for learning.

Introduction

The concept of zone of proximal development (ZPD) as developed by Vygotsky relates to the tasks that can and cannot be done by a child with the help of more able peers (Vygotsky, 1978). The ZPD allows us to look at the potential aspects of learning that can be brought out with a slight nudge to the learner. These nudges essentially are in the form of social intercourse with peers, who might know more than the learner about a given task. Vygotsky's original studies were conducted in environments in which the zone was elaborately constructed to enable this transfer of knowledge. In this study we explore a digital workspace which by design facilitates learning by creating a ZPD.

We provide two case studies, both based on sharing the work in a collaborative computer-mediated environment in a classroom setting under contrasting conditions. The two examples exemplify the role of connected computers in bringing meaningful and intrinsically motivating collaborative interactions towards a learning objective. Case study methodology was used in this study. In the first case study, involving an arithmetic game we have a pre and post test involving arithmetic proficiency. The data collected also included audio recordings, observer notes and logs from the computers. In the second case study, involving Indic typing the data collected includes observer notes, video recordings and logs from the computers.

The theoretical framework derives from the concepts of ZPD (Vygotsky, 1978), scaffolding (Bruner, 2009) and CSCL (Stahl, 2006). Vygotsky (1978) defines ZPD as: *"The distance between the actual* *developmental level as determined by independent problem-solving and the level of potential problem solving as determined through problem-solving under adult guidance or in collaboration with more able peers."*. Bruner (1985) introduced the term, scaffolding, as a metaphor of support a tutor provides to a learner till successful completion of a learning task. Scaffolding *"is help which will enable learners to accomplish a task which they would not have been quite able to manage on their own, and it is help which is intended to bring learners closer to a state of competence which will enable them eventually to complete such a task on their own."* (Maybin et al, 1992).

In this conception the focus is on the individual learner and usually the more able peer is the teacher or the mentor and hence is *asymmetrical*. Symmetry in this process would mean that both the peers are at the same learning level. Asymmetrical here implies the more able peer is at least one level above the learner and not at the same level. Newman et al (1989) suggest that ZPD should be expanded beyond individual and asymmetrical focus. They argue that even groups of learners can be considered as units of analysis and learning can happen symmetrically. In this case the symmetric would mean that the interacting peers are at the same level of conceptual development. Fernández et al (2001) suggest that idea of scaffolding can be used to understand how groups of learners can use language to support shared thinking and learning. Maybin et al (1992) suggest that learners in a group can understand concepts and complete tasks using linguistic 'scaffolding tools'. These tools include questions, feedback and explanations of the structure of the task. We have used their framework to analyse the tasks in our study.

How do the ideas of ZPD and scaffolding change on introduction of connected computers for interaction and also for setting of the learning tasks? Studies in the field of Computer Supported Collaborative Learning (CSCL) look into this angle (Stahl, 2006; Stahl et al, 2006). In CSCL context, group cognition exists at three levels, individual level (talking to ourselves), small group level (group discourses) and community level (adapting to community way of thinking, doing and interacting with the community). The focus, in this approach, is the actions of a small group mediating between the two levels (individual and community) (Stahl, 2006). In the first case study involving the arithmetic game, community level is absent while in the second case study of Indic typing all three levels are present.

Study 1: Learning arithmetic in a collaborative environment

The first study was done with primary school children of a semi-government school. An instant messaging game was designed and developed to help students learn arithmetic skills (addition, subtraction and multiplication). The study was done with 24 students of grade 4 age ranging from 9 to 11 years. Each student worked on a XO (laptop) for 45 mins every alternate day. They were connected with each other through WiFi. Students' proficiency in arithmetic was measured before and after the intervention and computer logs were collected throughout the intervention. Students and teachers were interviewed at the end of the intervention. The data analysis showed that the intervention leads to a significant improvement in students' proficiency in arithmetic (Shaikh et al, 2017). Students developed better strategies to solve arithmetic problems and those strategies diffused rapidly in the classroom.

The learning game proceeds as follows: Any one student starts and announces arithmetic game letting other interested students join. Nature of the game is similar to guidelines given by Kirriemuir & McFarlane (2004), though we did not know about these guidelines when the game was designed. For an addition game, the students decide a starting number and a stepping number. This decision happens through a verbal discussion in the class. The game starts once the starting and stepping numbers have been decided. The students keep on adding the starting and stepping number and type the results in the game interface. For example, if the starting number is 7 and stepping number is 3, a typical entry by a student would be: 7, 10 (7+3), 13(10+3), 16(13+3) and so on. The aim of the game is to get to the first three digit number of the series. The game is paused when any participant announces winning or someone points out mistakes done by other players. In both the cases, all the participants examine all the posts of student in question and through consensus decide whether computations are correct or not. The game proceeds till every student has achieved the end goal of reaching a three digit number. A new game starts with a new set of starting and stepping numbers and the game continues.

The important design feature of the game is whenever any student posts anything on her laptop screen; it is immediately visible to all the other participants. Each student's posting has a specific color, which helps in differentiating and identifying different students. Starting number, stepping number and the last calculated number of the game are continuously displayed on the screen, which makes the calculations easy by providing accessible relevant information. When students post their answer, it stays in the history of the game accessible to the players or mentor for scrutiny, learning and feedback. Access to the history of students' actions is the new affordance of the digitized version of the game. If students want to win the game, they have to perform faster and accurate calculations. At the start of the game learners use the strategies known to them for calculating and posting. As the game progresses, when learners have access to the shared response from their peers, we see a change in their strategies. When a student senses from the postings that someone else is doing same arithmetic problem faster, she goes to that student and asks her about it. In general, the 'more able' peer is highly motivated to share their strategy. We have observed students using strategies described by Shrager & Siegler (1998): *Sum, Shortcut sum, Min, Count from first, Retrieval*. Apart from these known strategies we discovered another strategy during this task, use of *Multiplication Tables* to aid certain addition problems (in which the starting and adding numbers are the same) (Shaikh et al, 2013).

Study 2: Indic typing as collaborative puzzle solving

In the second study, we look at an introductory exercise in a digital literacy course for students of 9th class in government schools. This digital literacy course is part of a much larger project initiated to enhance school science, mathematics and English language learning using computers. The course had 16 sessions, of which each session lasts for about 90 minutes. We studied about 6 such classrooms in a rural area of Rajasthan state in India.

The current focus of the case study is the part where the learners are introduced to operating the computers and to the course platform where all interactions happen. The course platform is based on a server in the school and connects with the rest of the computers via a Local Area Network (LAN). The learners are given individual logins for the platform to create an internet like experience. The platform presents the course content to the learners in a structured manner like an online course. The platform features include writing a notebook entry, commenting on pages and notebook entries, uploading files and giving rating to comments and uploads, and adding relevant tags. These features enrich the interactions on the platform by motivating and incentivizing communication in multiple ways. Each user on the platform gets points for adding notebook entries, comments and file uploads. The users can see these points after each activity, thus allowing them to see their progress continuously during each session.

The students were allowed to talk to each other during the class and the teacher played the role of a facilitator to inform students about the task on a large TV display in the computer lab. At times the teacher helped the students with some technical details. Help material in the form of animated gifs were available on the platform. The learners also have access to a Student Handbook and large posters displaying the keyboard map. If we look at the three levels of learning (individual, group and community) for analysis as given by Stahl (2006), we find that learning happens at all three levels.

The digital literacy course is designed assuming that the learners have had no experience with the computers. The digital literacy course is presented in a bilingual mode and learners can respond to the typing tasks in either English or Indic languages. We have used the Inscript keyboard layout for typing of Indic scripts (Inscript Keyboard Layout, 2017). The Inscript layout provides a universal method of typing most Indian scripts. The Indic script in use there is Devanagari.

In our design we have tried to incorporate the expression of ideas of the learners as a context for typing. In this way, each learner and group had a unique text to type. Some of the contexts that we provided were writing about themselves (where are you from, what do you like, what are your hobbies etc.), writing stories from pictures, asking and answering questions based on a given text, etc. But the actual action of typing the words in the Indic script can itself be seen as an overarching puzzle-solving exercise. Overall, typing even simple words in Indic or English script can be challenging for beginners, as they have to 'hunt' for the required keys. For writing complex words in Indic scripts, particularly ones involving the combination of two or more letters, one needs to know the rules of combination. The learners are provided with a printed version of the Inscript keyboard layout which they can refer to while working. We present here a summary of our observations.

The learning to type in Indic scripts can be seen as a four step exercise, increasing in the degree of difficulty:

1. Finding the mapping of each letter (consonant and vowel) on the printout and also on the keyboard.
2. Pressing Shift + Key produces another letter.
3. Knowing that the modifiers of the letters always come after the letters.
4. Using the *halant* modifier (half-consonant) to combine any two letters.

Learners slowly discover these rules by either carefully studying the printouts and mapping them back on the actual keyboard or by trial and error. When groups of students get stuck with a certain combination they seek help from other groups or teachers. But just knowing how to type once is not sufficient, learners have to practice typing, otherwise they tend to forget what they have learned. The typing sessions were the first in the sequence, while the other sessions require this skill. As a result the practice of typing continues throughout the length of the course, which is about 16 sessions in all. Only by third or fourth session in the course, the first time learners can type full sentences with ease.

The design of the learning task invokes varied and sometimes unique challenges to the students. The fact that each group has a different content to type makes the setting rich for peer learning. A typical difficulty that one group is facing might be solved by another group. This creates a *dynamic* ZPD where the roles of the peer change between mentor and mentee. We call this ZPD dynamic as the roles of individual and groups change during the process of learning. There are no fixed roles, a 'more able' learner or group might seek help at a later point of time.

There are two modes of communication which we observed during the sessions. The first one was direct talking. This included asking for help from other members of the group, and from other groups in the class. Overall, it was observed that any new 'discoveries' made by any group, transmitted to others very fast. This typically happened by either, the discoverers' announcing it in the class *"This is how we made this word!"* or someone looking at the typed responses on the platform and asking *"How did you do this?"* by approaching that group. Approaching another group and looking at how they solved a problem (as evident by their post on the platform) was a common sight. There was an overall free flow in intra and inter-group settings. Most of the conversations that we observed in this case were of the exploratory kind (Fernández et al, 2001). This flow of ideas and knowledge was made possible by the platform, which allowed the learners to share and see the work of others. Without this sharing, it would be extremely difficult to elicit such responses from the students. Similar observations are made in our first case also.

Typically the learning task here demanded switching between and using multiple representations and modalities. Given a context, the ideas to make stories are formed in the minds of the individual learners. At the group level, there is an exchange of these ideas, verbally, and the final story is created after negotiations. The worksheet asked the groups to write their stories in their paper notebooks, which allowed externalisation of the stories from the minds of the learners, which makes it accessible to the group allowing for distributed cognition (Hollan et al, 2000; Hutchins, & Klausen, 1996). But there are several other reasons we ask the students to write their stories in their paper notebook. First is that it makes easier to type something that is ready. To type and think what to type at the same time is cognitively demanding for learners who are new to typing. The second reason is to provide a bridge between the text of physical paper notebook and the text on the computer screen. The computer content is not something special, but any content made by the students can be brought to the computer. This in a way demystifies the idea of a computer as an alienated device. This mediation of text from physical to digital is a good entry point to making the computer a device of their own. The third major reason is that writing is a highly involved cognitive task. According to Dix (2006), the first order of cognitive task is inner speech, second is public speech, and the third-order cognitive task is writing. In this framework writing is considered a third-order cognitive task. Writing things out helps us clarify many things and are different in kind than talking.

The text that they have written in the paper notebook challenges the students to find the keys to create the required words. This is mediation from notebook to paper printed keyboard map (having both Indic and Roman scripts) to actual keyboard (having only Roman keys) which happens via collaboration between the learners. In many groups we observed that one member looks at the printout, while other types the letters, and the third member tells what to type, this way the typing activity is like a *collaborative puzzle solving*. The final form of text is seen on the screen, where the learners can check the validity of their efforts immediately. The immediate feedback and chance to act on the feedback by editing their posts on the platform is helpful in consolidating the learning. In some cases we noticed that even the teachers gained new knowledge from the learners as the teachers underwent training to conduct these activities not too long ago and were not very conversant with computers or lacked practice.

The learners are encouraged to look at the posts made by their peers, where they can comment on the work of their peers. This provides another level of collaboration between the learners. They point out ways on how the text can be improved, mistakes in spellings fixed. This exercise creates a safe space for making mistakes which can be rectified. Learners also build negative expertise in avoiding common errors (for example, adding modifiers after the letters) in this exercise. A congratulatory word in the comments provides positive reinforcement for the learners. Thus we see that such an experience provides the learners with very rich experience of entry into computers where their own and peer knowledge forms the basis.

Discussion

We have looked in this article the possible ways of creating and curating a digital space for collaborative learning. The ideas of ZPD and scaffolding are played out in a digital space which allows the learners to make mistakes safely. In this context the role of the 'learned peer' is a *dynamic* one, with different learners playing the role at different times, as opposed to Vygotsky's (1978) asymmetric and Newman et al (1989) symmetric one. This allows for greater participation in the class from all groups and individuals. Also, such an environment presents a space for 'learned peers' to share their knowledge among others, such a space is usually absent in the traditional classroom. Though the context of the two studies we presented here uses different online platforms, the essential aspect in them is the *idea of sharing of the progress towards achieving a learning goal in a digital public space*. This makes the peer-feedback, self- and peer-learning possible. Such an approach provides essential scaffolding for the entire class to make mistakes and learn from them.

Instant sharing of the ongoing progress to achieve the goal plays an important role in this interaction. This sharing of work allows the formation of a ZPD by allowing learners to view and analyse faster strategies, and the dynamic interaction with peers helps the learners realize their potential. Posting on a computer screen also plays an important cognitive role, it frees valuable mental resources for doing tasks like mental calculations, deciding which strategy to use for given problem etc. (Hutchins, 1995). Same effect may not be possible when the game is played with pencil and paper, for example, it cannot be played by a large number of learners, work cannot be shared instantly with everyone, and the speed of response is very limited.

In both the studies, the externalisation of the problems, doing the sums online, and typing out their thoughts, helped the learners to visualise the process of learning. It is only by shared digital externalisation that such a process is possible. Concretisation of their own learning in the form of tangible and reproducible results helped the learners to accomplish the tasks by following the more competent peer or peer group when needed. This process inherently also allowed for self and peer-assessment, as the output of each individual and group were on public display and correctable by peers. Due to the digital nature of externalisation, correcting a mistake is much easier and doable. This externalisation acts as a scaffold when peers are symmetric in their level of conceptual development, in contrast to the Vygotskian model. This scaffold might be helpful immediately to certain peers, but due to 'permanent nature' (as compared to mere verbal help) it creates a lasting learning scaffolding which can be used later asynchronously by other peers. For example, a note or comment left by the peer can be read and be useful much later. One can think of such learning as being 'incidental', and it is only possible because of accessible externalisation. This can be seen as analogous to the various online help forums, where learners can get the required help by just browsing the older posts.

The self and peer assessment in this context also allowed multiple ways to correct possible mistakes by looking at peers and peer groups. For example, discovering multiplication strategy when using the same starting and stepping numbers. The public display also allowed others to actively point out potential mistakes and possible solutions for them, thus developing a "negative expertise" in the process (Minksy, 1994). For example, pointing out an incorrect combination of letters or spelling and telling a way to correct it. This cycle of feedback and subsequent corrections, is *emergent* and *dynamic* scaffolding which allows the learners to successfully complete the task. We call this scaffolding *emergent* as it evolves from interactions among the peers, where the roles of being a 'more able' peer are dynamically changing for different tasks.

Due to the nature of the tasks involved, it allowed the learners to accomplish the task in different ways. In the Indic typing study, for example, each of the individual and the group had a different thing to write. This created a variety of opportunities to learn from and also changed the problems that each group faced, for example, the need for a variety of combination of letters. The variety of the problems created new and challenging learning opportunities for the individuals as well as the groups. In case of the arithmetic study, different strategies were developed and discovered by individual students, which were discovered by peers. What we observed in both the studies is the urge to share the newly discovered strategies and solutions with the immediate group and the community. The rapid diffusion of strategies and solutions in the classroom was instrumental in making the collaborative learning possible. This diffusion was not pre-mediated by the mentors, but was emergent, natural, and spontaneous. In a regular classroom there are hardly any opportunities for such interactions to materialise, as there is monotonicity in the solutions to the tasks. In a regular classroom the avenues for collaboration are limited if there are any at all. Keeping these two points in mind while designing activities, it will provide richer engagements and learning opportunities to the students. We have seen these observations in two apparently different studies but similar in their design principles.

Further work is needed to see how the learners retain learning gained during these interventions. Another direction of investigation is to look at whether learners are able to transfer the learning to another task or domain. The preliminary observations from Indic typing study show that they could submit the remaining course assignments by typing in Indic languages. In case of arithmetic game, further study is needed to establish the transfer of knowledge to another problem solving contexts. In both our studies the levels of learning as indicated by individual, group and community were part of the same classroom. We would like to study how this scales when the community is no longer limited to the immediate classroom environment of the learner.

Acknowledgements

The Indic typing part of this paper is based on the work done as part of Connected Learning Initiative (CLIx), a technology enabled initiative for scale for high school students. The initiative is seeded by Tata Trusts, Mumbai with Tata Institute of Social Sciences, Mumbai and Massachusetts Institute of Technology, Cambridge, as founding partners. We are thankful to OLPC Foundation and Harriet Vidyasagar for the laptops used for the arithmetic case study.

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ACTION RESEARCH ON MIXED AGE GROUP (MAG) CLASSES FOR MATHEMATICS IN MIDDLE SCHOOL

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Three mathematics teachers discussed the need to address the common perception of mathematics as an intimidating subject, even as they worked with children of different skill levels and worked towards preparing them for the Board Exam in Grade X. While such challenges exist for all subjects, mathematics seems to have gained a special status as students move from concrete to abstract concepts. The linear manner in which the mathematics syllabus is typically laid out probably adds to the fear of not being able to "catch up", once a student falls behind.

Out of these discussions was born the idea of an action research (AR) project where grouping children vertically (mixed age instead of same age) in the middle school could enable necessary scaffolding and help with a smoother transition into high school. A three-year study was planned so as to allow the first group of Grade VI students to complete three consecutive years of the mixed age group (MAG) experience before they moved to high school (Grade IX). The research carried out in the first two years is described here, along with possible implications for the third year.

Introduction

Our school is a not-for-profit organisation in an urban setting and comprises about hundred and fifty students, with about fifteen students per class. The school has been supporting children from all socio-economic backgrounds, including first-generation learners. An inclusive community, 1% of each group comprises students who have special needs.

Given the special place that mathematics seems to hold in the minds of children, parents and society at large, this research was undertaken to effect greater enjoyment in teaching and learning the subject, with opportunities for children to learn at their own pace. The three teachers (referred to as "we" through the document) who are currently part of the MAG implementation are the authors of this document. We have been teachers of mathematics for one, four and seven years respectively, and have been teaching grades six to twelve. A facilitator met us approximately once a month guided us through the entire AR documentation process and also shared relevant research papers with us every now and then. Given our packed schedules, we did not have occasion to interact with Mathematicians or academics in order to inform our research further. This paper is laid out in the typical flow of AR, Costello (2011), viz. plan, act, observe and reflect.

Planning

Objectives for the MAG classrooms

In the 2014-15 academic year, we observed that a significant number of students from grades V to IX required additional help in mathematics, either in class or outside regular classes. This necessitated additional 'support teachers' to provide remedial help. For example, while some children worked on finding square roots of decimal numbers, others in the same class grappled with whole number arithmetic. If number types and their arithmetic are viewed in a linear fashion (whole Numbers → integers → rational numbers), this disparity in the same class translates into roughly three levels of mathematical skills. This resulted in considerable splitting of the teacher's time and attention, leading to a reduction in time spent on instruction for each level. Often, this demanded increased after-class support. Hong et al (2012) highlight the positive effects of increasing time spent on instruction– we observed the converse effect as our instruction time in class reduced. Out of this situation was born the idea of carrying out AR with a vertically grouped (Martin & Pavan, 1976) or 'mixed age' class with the following objectives:

1. To provide every child in middle school (Grades VI, VII and VIII) the opportunity to work at his/her pace and revisit topics in Mathematics until the child is confident and ready to move to the next skill level.
2. To reduce, if not eliminate, the need for remedial classes and work with children, inside the classroom,at the level that they are comfortable with.
3. To help reduce the load of a differentiated lesson plan and consequent splitting of a teacher's time, so that she/he may focus on - at most - two levels of skills at a time.
4. To reduce the fear of mathematics and help a child engage actively and positively with the subject.

Planning for the MAG classes:

Planning for the MAG classes involved the following:

1. With our school's flexibility that permitted teachers to choose textbooks and appropriate reference material, we decided to use the National Council of Educational Research and Training (NCERT) Mathematics textbooks for Grades VI, VII and VIII as our reference books. Here, the linear layout of topics spanning Arithmetic, Algebra, Geometry and Statistics - such that each year begins where the previous year concluded - made our planning simpler.
2. At the end of each year, the three MAG teachers examined the math topics that they wanted to cover in the following year, and aligned the transaction such that similar topics would be handled simultaneously, with gradually increasing levels of challenge. This was done because it was noted that aligning the topics would make it easier for a child to move across groups at the beginning of each new lesson. For instance, one such flow was: basic geometrical ideas for the first level, lines & angles, triangles and its properties for the second level and understanding triangles and quadrilaterals for the third level.

3. We moved between Geometry, Algebra, Arithmetic and Statistics to give children variety. We also hoped to understand if obvious areas of interest or strength arose (e.g. some children like Geometry more than Algebra; some have stronger Arithmetic skills, etc.)
4. Once the annual plans were in place, the teachers wrote out their lesson plans for each topic, ideally a week or two ahead of the classes. Since MAG helped reduce the number of levels within a class-typically limiting it to two levels-common lesson plans could be made for the entire class. Appropriate worksheets were designed to provide necessary scaffolding for children who required more practice and/or time with a topic.
5. The final step in planning was to ensure that timetabling was done such that all three classes (VI, VII and VIII) had their mathematics periods at the same time. This made it possible for a child to move across groups during Math class alone.

Student involvement

Students are a critical part of the AR and their buy-in into the idea plays a key role in its success or failure. The initial discussion around and resultant decision to implement MAG involved only the teachers and Principal. These discussions happened after the end of the 2014-15 academic year. The students were introduced to the idea during their first Mathematics class, once the new school year started in June 2015. [Refer *Observations* section for details of these interactions.]

Ever since, we have been following this process of introducing the idea of MAG and inviting questions and suggestions from all, as a new batch of Grade VI students joins the group every year and the previous year's Grade VIII leaves the group.

Parent involvement

It is important for parents to get involved in the MAG discussion early on, both to understand what is happening in their child's mathematics class as well as to support the child, as needed, all through the year. We therefore involved parents at every step of the MAG process: having discussions at the beginning of the year, following up during parent teacher meetings (twice a year) as well as inviting formal feedback at the end of each year of MAG.

Action

Implementation of MAG

The teachers conducted preliminary tests for each child in the three same-age groups. We experimented with the type and frequency of the preliminary tests, switching from topic-wise to stream-wise (Algebra, Arithmetic, Geometry) tests; multiple tests to a single one at the beginning of the year; individual papers at different levels to a combined paper with questions at different challenge-levels. Irrespective of the type, nature and frequency of these tests, evaluation did involve a subjective component. While broad rules were followed to use objective data as far as possible, exceptions were made so that no child felt coerced into joining a specific group.

Based on these tests, the teacher suggested an appropriate group for each child and followed this up with a teacher-student discussion on how this decision was reached. The teacher gave each student an overall summary of the areas that the child would benefit from revisiting, or working on at an advanced level – as the case may be. Table 1 outlines one possible scenario.

Grade VI Group	**Grade VII Group**	**Grade VIII Group**
Topic: Fractions	**Topic:** Fractions	**Topic:** Fractions
Concepts covered: Introduction to fractions; addition and subtraction of like fractions	**Concepts covered:** Addition and subtraction of unlike fractions; introduction to multiplication of fractions	**Concepts covered:** Multiplication and division of fractions; properties of rational numbers
Pre-requisites: Basic understanding of division	**Pre-requisites:** Representation and interpretation of fractions; identification of fractions	**Pre-requisites:** Perform Arithmetic operations like addition, subtraction and multiplication on fractions; decode and solve word problems
Student A: Already familiar with concepts at this level	**Student B:** Comfortable with concepts at VI level, needs to practice addition and subtraction	**Student C**: Not comfortable with pre-requisites. Will benefit from revisiting concepts at grade VII level
Move to Group VII	**Stay** in Group VII	**Move** to Group VII

Table 1: Student movement across groups (named according to grade, but constituting children of mixed ages)

The Teacher's Role in MAG-AR

Initially, MAG-AR appeared to warrant a mere rearrangement of classes, but it later became evident that it necessitated much more: from a significant change in the teacher's approach to teaching, to considerable interfacing with multiple stakeholders: the school management, students, parents, teacher colleagues, the AR facilitator and fellow AR researchers.

Observations

All observations in this section have been recorded for the two groups that have been in MAG for two continuous years. These groups were in Grade VI and VII in the first year of MAG.

Students

During our initial discussions with students in the first year, some children were anxious that they would be "sent back" to a lower class. Teachers explained that no child will be "sent back" or "demoted". During their mathematics class alone, each child would work at the level that they were comfortable with. This could involve revisiting a topic covered earlier, visiting a new topic with the current class or moving to an advanced level in the topic. Though the children did not explicitly express such concerns in the following years, they continue to be anxious about having to work with a younger class. As seen in Figure 1, we observed that more students were willing to make the change across groups in the second year of MAG. [Students in the VIII grade could not move up as they were the senior most group in MAG]. During this process, cases of teasing were brought to our attention. These typically involved one student pointing out to another that he/she needs to work at an easier level or that the problems they work on are "so simple".

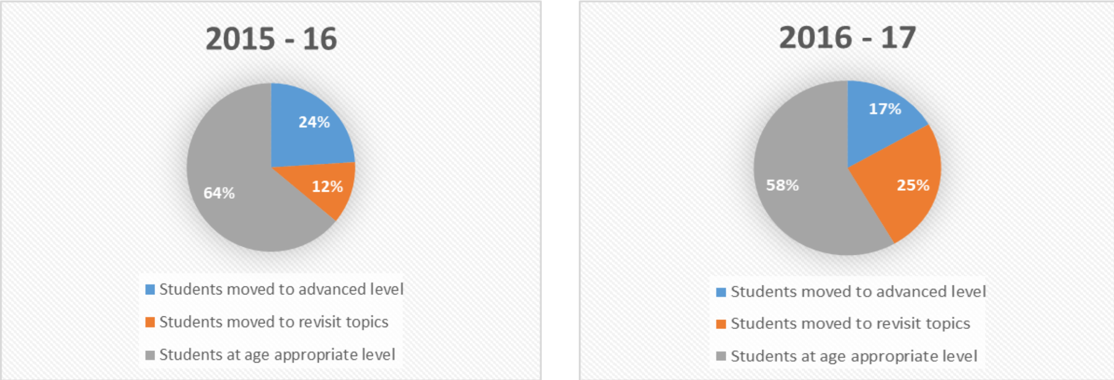

Figure 1: Student movement across groups

Students who worked at an advanced level had also been heard boasting about their 'challenging' math classes. In each of these cases, teachers typically had a circle time with their individual classes or held joint sessions with all three classes, pointing out that the idea behind MAG was to help each child get comfortable with (and gain confidence in) mathematics. Here, we confirmed Theilheimer's (1993) findings about how students themselves come up with solutions during such circle time discussions. We reached out to students, asking for their help by helping their classmates out, as against lowering their self-confidence.

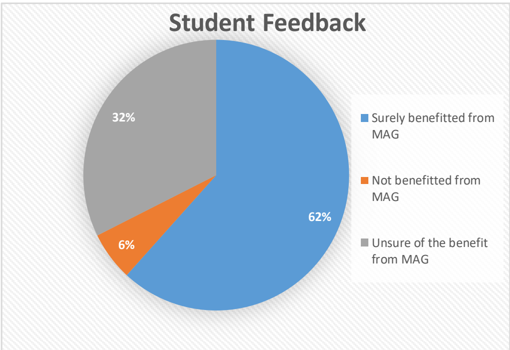

Figure 2: Student feedback after 2 years of MAG implementation

Figure 2 shows the feedback from students at the end of two years of MAG. Students were requested to provide subjective as well as objective information (see Figure 2 as well as *Conclusion* for examples of both) on whether they believed that they had benefitted from MAG. A few students who remained in their age-appropriate class were unsure if they had benefitted from MAG. Since they had not moved across groups, they were not able to determine if things would have been different had the classes been Single Age Group classes (SAG). The teachers, however, believe that they were able to spend more time with these children in the MAG classes as their attention was not split across multiple levels, as would have been the case in SAG classes.

Students' progress over the two years was also recorded in terms of the following parameters:

- Test/Exam performance: improvement in test scores, reduction in repeated errors and reduction in assistance required during tests
- Subjective parameters: improved and active participation in class, willingness to take up new challenges (typically,seeking out more work)

Sample data for these parameters is shown in Table 2, covering a period of two years.

Student	**Exam Score**	**Repeated Errors**	**Assistance during tests/exams**	**Subjective parameters**
Student X (Stayed in age-appropriate group)	46% at the end of first year to 55% at the end of second year	Reduction in repeated errors in Fraction and Decimal Arithmetic (e.g. $\frac{3}{6} = 2$)	Graduated from requiring most questions explained during a test to fewer clarifications sought out during the test	Became more regular with assigned work; started enthusiastically raising his hand to answer questions out of turn
Student Y (Moved to revisit topics)	51% at the end of first year to 61% at the end of second year	Reduction in errors related to adding algebraic terms (e.g. $2x + 3x = 5x^2$)	Graduated from requiring most questions explained during a test to fewer clarifications sought out during the test	Proactively completed corrections; increased confidence while answering questions
Student Z (Moved to advanced level)	Consistently above 80%	Errors related to rushing through the paper reduced; child started revising his answers patiently	Child was given the opportunity to engage with the topic at a deeper and more challenging level. Required minimal or no assistance during test	Highly engaged in class; challenged the teacher on various topics, expressing a desire to dive deeper.

Table 2: Sample student progress over two years of MAG

Based on this progress, students were grouped into three categories: *Beginning*, *Developing* and *Proficient* – reflecting increasing levels in the above parameters.

Figure 3 below shows an increase in the proficient category from 2015-16 to 2016-17.

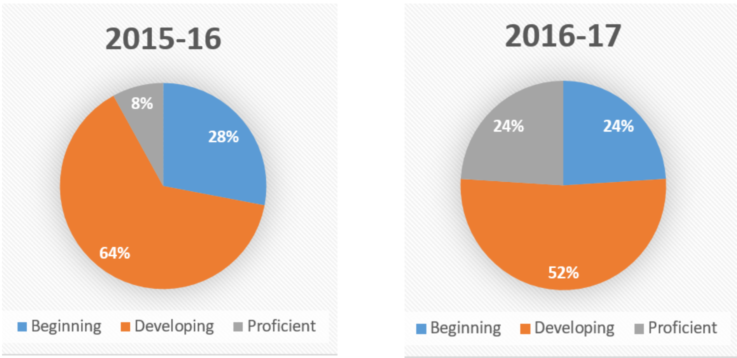

Figure 3: Student progress (category-wise) over two years of MAG

Students with Special Needs: Students with Special Educational Needs (dyslexia, dyscalculia, attention challenges, etc.) still require one-on-one attention in most cases. In the case of these children, the need for remedial help and additional support teachers continues to be experienced.

Reflections

While information has been laid out linearly for the purpose of this document, the AR Plan-Act-Observe-Reflect cycle (Costello, 2011), in reality, occurred as multiple cycles, sometimes one within another, and at other times, as interlinked cycles. This being our last year of the MAG AR project, the following salient points remain to be analysed:

Reaction to MAG Grouping:

In the process of grouping children based on their comfort levels with various mathematics topics, our implementation has resulted in an explicit grouping of children into three levels – which has had two fallouts. One set of parents and students have welcomed the clarity that this process has provided, as it has helped them understand what needs to be done and how. Another set, however, is uncomfortable with such explicit grouping and have reacted with increased anxiety over each group change. Reasons for a student's discomfort include: working with a younger group, moving away from their group of friends/classmates and a mismatch in their self-evaluation and classroom performance. We hope to understand over the three years of MAG if the reactions of each year are independent of the previous year, or if mindsets tend to veer towards greater acceptance, based on how long an idea has been around. The percentage of students expressing dissatisfaction over their group change, over the two years remained more or less the same (around 67%). Their reasons were:

- Children with special needs required more than one year of scaffolding at a lower level. However, this meant they would need to work two levels lower in the second year. They agreed to move one level but not two. Their choice was respected.
- Children who moved up one level for some topics in the first year believed they could "cope" with *all* topics. They were dissatisfied when advised to work at their age-appropriate level.

Meeting Objectives of the MAG AR:

We worked with students from middle school with the hope of seeing a difference in comfort and confidence levels, with mathematics, when the students moved to high school. Table 3 captures a summary of our objectives and the extent to which they have been met in the first two years of MAG.

Objective	**Met / not met**	**Evidence**
Provide every child an opportunity to work at his/her pace until the child is confident and ready to move to the next skill level	Yes	Data from student movement across groups (Figure 1), student feedback (Figure 2*:*) and student progress (Figure 3) indicate a positive trend
Reduce the need for remedial classes and work with children inside the classroom at the level they are comfortable with	Yes, for students who need more time with a topic No, for students with special needs	Data from student movement (Figure 1) indicates an increased flexibility to work in another class instead of making time outside class to catch up
Reduce the load of a differentiated lesson plan and splitting of a teacher's time; allow a teacher to focus on at most two levels	Not met for all teachers	Factors that still warrant a differentiated lesson plan and teaching strategy: - too many children in a class (e.g. children move into VII from both VI and VIII) - children with special needs - children who are disinclined to work and are in a prolonged catch-up mode
Reduce the fear of Mathematics and help a child engage actively and positively with the subject	Yes	Data from student feedback (Figure 2) and student progress (Figure 3), in-class participation and student attitude indicate a positive trend

Table 3: Meeting Objectives of MAG

Conclusion

With one more year of the AR still to go, it is rather difficult to conclude about the success of the project, and this paper describes work in progress. The AR process, however, has resulted in tremendous learning for each teacher involved: necessitating our continuous discussion and updates – and this has helped provide considerable clarity on various challenges and strategies. This rigorous planning, strategizing and implementation has benefitted not just the students but also the teachers involved as well.

Over the two years of MAG implementation, parents and their feedback have also been an important part of the project. Mixed impressions were obtained from them. Some parents appreciated the opportunity and additional help that their child receives by revisiting topics at a lower level and believe that this experience has increased their child's self-confidence. Others have expressed concern if their child worked at a lower level and have therefore tried to help their child strengthen their mathematical skills. Further, some parents have seen this implementation as an opportunity for their child to be challenged beyond their comfort zone and have actively tried to push them to a higher level. Some parents have come back and told us how visibly excited their child is with working at a higher level in maths.

From the student group, we have received both reassuring and conflicting feedback so far. While some students expressed positively, for example: "I felt MAG has increased my self-confidence" and "MAG is awesome and challenging", others preferred the conventional format: "I'd still rather be in my own [age-based] class" or "this is merit based grouping".

Acknowledgements

The authors would like to thank Dr. Indira Vijaysimha, Founder and Trustee, Poorna Learning Centre, Ms. Jayanthi Sachitanand, Director, Poorna Learning Centre, Dr. Neeraja Raghavan, Founder-Director, Thinking Teacher and Mr. Vinay B.R, previously teaching at Poorna Learning Centre, for their inputs and guidance through this action research project.

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A NOVEL EDUCATIONAL APPROACH USING PARENTAL OCCUPATION LINKED LEARNING FOR LOW SOCIOECONOMIC STATUS CHILDREN IN INDIA

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A novel educational approach using Parental Occupation Linked Learning (POLL) was developed for use in the middle school science education in select schools of the Ballabgarh Block (sub-district) in Haryana state in India. Typically, state-run schools utilize a teaching methodology based on activity based learning, but low test scores in science among low socioeconomic status children, who are primarily first generation learners, suggested a failure of the existing teaching methodology. POLL directly links a student's parental occupation with teaching of scientific principles, framing curriculum in familiar terms based on parental occupation.

Literature Review

Integrated education

The need for education to be being linked to surroundings was raised by both Rabindranath Tagore and Mahatma Gandhi. Rabindranath Tagore laid emphasis on the practicality of education, i.e., centred on the whole *physical and social milieu of the student in which the student's life was lived. (*Jalan, 1976). Tagore further expanded on the concept of sub conscious learning – learning that comes from surroundings of a student. Mahatma Gandhi formulated *Nai Taleem*, or 'integration of the world of work with the world of knowledge', (Gandhi, 1937) a concept echoed by both Kothari Commission (1964-66) and National Policy of Education (1968) but not implemented. Ishwarbhai Patel Committee introduced Socially Useful and Productive Work (SUPW) in schools but it failed to capture the spirit of integrated education envisaged by both Tagore and Gandhi.

Current state of elementary education in Haryana

The Right of Children to Free and Compulsory Education Act, or 'Right to Education Act' (RTE), ensured compulsory free education for children aged 6 to 14 throughout the country. By definition, all children of appropriate age, not enrolled in a non-Government supported school by their parents, are entitled to education in a Government school without any fees, charges, or expenses. The RTE also places the burden for ensuring attendance, admission, and completion of schooling in an elementary education on the Central and State Governments, which also share the funding responsibility. The RTE further creates standards for education, including norms for Pupil to Teacher Ratios for each school (not just averages across a Block, District, or State), infrastructure, teaching hours, school calendars, and prohibiting the operation of unrecognized schools, collection of capitation fees and conduction of private tuition by teachers.

In the state of Haryana, implementation of the RTE has been assigned to Block Elementary Education Officers/ Block Resource Coordinators (Department of School Education, Haryana, 2011), who are bureaucrats tasked with implementing and coordinating education at the Block level (sub-set of a District). These Officers and Coordinators are part of a cadre of officials across India responsible for the schooling of 100 million low socioeconomic status children, many of which are trying to overcome low earning potentials for any chance at equitable growth in India (UNICEF, 2011). A study two years after RTE implementation praised the government overall for being proactive, but found infrastructure, admissions, and teaching to be the key issues lacking in success. One specific recommendation was the focus on "activity orientated" teaching, and additional schooling for students from lower economic groups who have difficulty in understanding taught subjects (Seema, 2013). Haryana, in particular, suffers from relatively low enrolment of middle school age children compared to neighbouring states and India as a whole, according to the Gross Enrolment Ratio (Gakhar & Kour, 2012). As governments explore new ways to respond to this constitutional responsibility and implement the Act, relevant and useful educational methods are needed to engage these, primarily, first generation learners who have limited educational support at home due to unfamiliarity with school-related processes, expectations or opportunities.

Background for activity based learning

Activity based learning is defined as "any instructional method that engages students in the learning process" (Prince, 2004), which requires the student to participate actively in classroom-based activities, as opposed to passively listening to a lecturer. It is based on a cognitive-learning theory developed from "constructivist" learning theories (Hein, 1991, Stößlein, 2009). Activity based learning often offers more impact than traditional lecture-based teaching because it forces students to actively participate rather than sitting passively (Harfield et al, 2007). Furthermore, it employs tactile and real-world based experiences to help students retain knowledge for future use by combining it with previous experiences (Edward, 2001). The method is effective because it *"frequently involves the use of manipulative materials"* which can be very helpful for first generation learners (Suydam et al, 1977). Furthermore, this technique has been used successfully to navigate educational situations with students who use English as a second language, allowing the teaching method to involve activities that bridge language divides (Padmavathi, 2013). Activity based learning has been shown to significantly impact achievement in various subjects, including Physics, at a secondary level over traditional lecture based teaching (Khan et al, 2012). It has also been investigated specifically in India and shown to improve the quality of education (Awasthi, 2014). However, schools utilizing activity based learning teaching methods reported rather poor results in test scores with low socioeconomic status students in Haryana. These results were better than lecture-based teaching methods, but still not as high as desired by the Government.

Important factors for student learning

Studies in various low socioeconomic areas in India have shown that parents are an important stakeholder and component in successfully implementing RTE. Not only educating parents about opportunities for children, but connecting that education to the parents is a critically needed intervention (Bano, 2015). Additional studies have also marked several other factors as having a strong influence on student's learning. First is the cultural context of a student (Sternberg & Grigorenko, 2004), which takes into account cultural norms, traditions, and expectations in understanding the learning environment for a particular student. Second is the existence of a familiar domain, which plays on the strengths of areas of study or association the student is already familiar with (Parke et al, 2006). Third is world knowledge, which relies on general experiential knowledge of the student (Parke et al, 2006). Fourth is tacit practical knowledge, which is typically instilled in the student by daily observation, often without any verbalization or explicit instruction (Sternberg, 1997). Fifth is a student's self confidence in learning capacity, confident students are much more likely to learn and retain information than those who think they are helpless or unable to learn (Parke et al, 2006). Finally, it has also been shown that children actively try to fit new information in with knowledge they already possess, especially when encountering new scientific concepts (Parke et al, 2006). In communities that lack traditional educational opportunities, like schools, learning is often done through an apprenticeship type model, specifically when it comes to occupation and cultural learning in villages, like those found in Ballabgarh.

Methods

Development of POLL

POLL was developed in response to observations of student impulses and preferences during activity based learning styled methodologies for science education at the middle school level. Groups of low socioeconomic status students in Grade 7 in a state-run school in Block Ballabgarh (Haryana, India) were observed to respond and prefer enthusiastically to different materials (husk, clay, metal, etc.) during science lessons for density experiments and others. Upon closer inspection, it was determined that the groups of students responded to materials that were familiar to them, with direct correlation between familiar materials and the students' parental occupations. Based on these observations, it was hypothesized that linking familiar materials corresponding to students' parental occupation would improve efficacy of science-based lesson plans for teaching the scientific method and various scientific concepts. This novel customized educational approach was further developed in collaboration with experienced teachers at both private and state-run schools. In comparison to activity based learning, the POLL approach encouraged students to apply materials and concepts grounded in the child's parental occupations to teach concepts, physically connecting the educational process to the child's home life. Students were also separated into groups to learn together with others who come from families with similar occupations, reinforcing the learning process above what the activity based learning method can provide.

School selection for POLL

The POLL teaching method was deployed in four randomly selected Government schools (out of 26) in the Block Ballabgarh of Haryana. The four selected schools were Girls Government Middle School, Fatehpur Billoch; Government Middle Schools, Heerapur; Government Middle School, Khandawali; and Government Middle School, Pratapgarh. Within each school, sixty Grade 7 students were selected at random and divided equally into an experimental group and a control group. This division was made after teachers administered a pre-test to assess scientific knowledge. The pre-test asked students to provide the occupations of both parents and then included 20 multiple choice questions covering basic chemistry and physics that had been previously taught to the students in other Grades. The pre-test was then scored by the authors, who then ranked the students according to score, and separated all even-numbered students into the control group and odd-numbered students into the experimental group. The experimental group was taught using the POLL method, while the control group was taught using the existing teaching methodologies based on activity based learning. Results of the pre-test were analysed for statistical regression threat, but no clusters were found either at the top or bottom of the distribution, ensuring no issues.

Pilot testing of POLL

POLL was first tested as a pilot program in a separate school to prevent any biases from entering the study. An independent school, Government Middle School Chandawali, was selected for the pilot program. The students at this school were representative of the low socioeconomic status found in the primarily first generation learners that made up the student population in Ballabgarh.

Deploying POLL

POLL was introduced as an alternative teaching method to activity based learning for the middle school (Grade 7) science curriculum. In each group, students were taught four science concepts once a week in a 40 minute session for four consecutive weeks. Students were given an assessment immediately following the completion of the teaching and two months later to test knowledge retention provided by each methodology. To further eliminate bias of instructors, the same teachers, one at each school, taught the same science concepts to the experimental and control groups of each school in back-to-back sessions, using the appropriate methodology for each as specified by the study. The authors did not directly participate in the teaching methods and instead observed through classroom visits during both the activity based learning and POLL sessions. The lesson plans for the POLL method were created by the authors and provided to the teachers in advance. The students themselves were involved in a blind study.

List of occupations analyzed	**Abbreviation**
Carpenter	Cr
Farmer	Fr
Electrician	El
Mechanic	Mc
Painter	Pt
Plumber	Pb
Potter	Ptt

Topics Taught
Biodegradation
Conduction
Corrosion
Density
Diffusion
Elasticity
Gravity

Let us illustrate how POLL is used to teach one topic, say, density, using the Scientific Method.

STEP 1: Ask a question

The Question will be framed as per the dominant occupation in a student's home. Following are the questions framed for different occupations:

Cr: Why does wood float on water while an iron nail sinks?

El or Mc: Why does a boat float on water but a single nut sinks?

Fr or Ptt: Why does a lump of mud sink in water but small plants float?

Pb or Pt: Why does kerosene oil float on water but colour sinks?

THE SCIENTIFIC METHOD

STEP 1: ASK A QUESTION

STEP 2: DO BACKGROUND RESEARCH

STEP 3: CONSTRUCT A HYPOTHESES

STEP 4: MAKE A MATERIALS LIST

STEP 5: CONDUCT EXPERIMENT

STEP 6: RECORD RESULTS

STEP 7: ANALYSIS YOUR RESULTS

STEP 8: CONCLUSION

STEP 2: This will be same for all children from all occupations.

STEP 3: The essence of hypothesis will be same for all occupations except that each occupation will use occupation-specific materials, e.g., tarpin oil for Cr, paint for Pt or Pb, and so on**.**

STEP 4: The materials used will be occupation specific:

Cr	**Fr or Ptt**	**Pt or Pb**	**El or Mc**
Wooden pieces	Sand or Clay	Paint	Nuts
Tarpin oil	Mineral oil	Kerosene Oil	Iron Nails
Wooden waste powder	Water	Pipe pieces	Machine Oil
Fevicol	Dry leaves	Pipe Wrench	Petrol

STEP 5: The experiment will be conducted using occupation-specific materials

STEP 6: Results will be recorded using a similar procedure for all occupations.

STEP 7: The results will be analyzed in a manner similar to all occupations.

STEP 8: The conclusion will be the same for all occupations

POLL, frames questions, constructs hypotheses, conducts experiments, uses materials and conducts experiments aligned to a student's parental occupation, thus making learning a naturally familiar process for a student. It is pertinent to note that POLL is not about making students learn their parents' occupation; it is about learning science concepts linked to parental occupation, thus enhancing learning outcomes in the process.

Results

Observations from POLL

A. Improved understanding

"I have noticed a sea change in the ability of students to make connections of the topic under discussion with the real world. The reason is simple: POLL has direct connection with the students' home which makes it easy for the students to make cross connections." – Teacher Sandeep Sir, Government Middle School, Heerapur.

"While applying POLL, I observed an immediate connect with students. As soon as a concept is linked to their parents' occupations, their eyes light up and they get engaged like never before." - Teacher Raj Rani, Government Girls Middle School, Fatehpur Billoch.

B. Contextual familiarity for children

"I came scared to class. But as I saw the experiment on density, I was relieved because all the materials are used in my father's occupation who is a plumber." - Sachin, Grade 7, Government Middle School, Pratapgarh.

"It was as if magic happened today – my home was transported in the classroom today! All materials are those used by my parents at home in their respective occupations." - Bano, Grade 7, Government Middle School, Khandawali.

C. Improved parental participation

"While doing the density experiment, I was thinking that I would need to buy the materials from the market (a challenge) until I realized that all materials are available with my parents at home." - Bharti, Grade 7, Girls Middle School, Pratapgarh.

"My husband and I are illiterates and were never involved in Pinky's learning. Until now, Pinky asks for materials that my husband and I use daily in our occupations." - Sarla devi, mother of Pinky, Grade 7, Government Girls Middle School, Fatehpur Billoch.

D. Government response

Anita Sharma, then serving as Block Elementary Education Officer- Ballabgarh, Haryana Government, believed this new methodology to be extremely important for schools, teachers and students within her remit.

Sharma said *"POLL is the best thing that has happened to my Ballabgarh block since I took charge on 27th March 2012. I have never seen a more impactful intervention related to improving learning outcomes in my 26 years as an educator and administrator. POLL is intuitively simple and revolutionary."*

Furthermore, feedback from students, government officials, parents, and teachers have been incredibly positive.

Discussion

This new teaching methodology, POLL was shown to be well-liked by students, parents, teachers, and school/Government officials as a result of this study and its associated methodology development. Feedback from all parties was incredibly positive overall, in interviews conducted after the study. While test results are still being collected and will be published in a follow-up study including comparisons of standardised test results between students taught with the POLL methodology and the standard activity based learning methodology, early data looks promising that the newly developed methodology provides for significant score increase for students.

Testing data is still being collected, along with standardised score data, but early results indicate the POLL method showed significant improvement across the board in correct responses to test questions given to participants in both the Experimental Group and Control Group.

Conclusion

POLL, a new teaching methodology, was developed to improve knowledge retention and educational quality for science education in middle school in low socioeconomic status children who are primarily first generation learners with illiterate parents. The methodology was extremely well received by students, parents, teachers, and school officials who were involved in the study. Most importantly, this new methodology provides a way for parents who are illiterate to participate in the education of their child, which reinforces the goals of RTE and of the education system as a whole. The same methodology can and will be used in future studies to test score improvement and knowledge retention in other age groups and other subjects.

Sample Questions of Pre-test

1. Density is:
   Mass/ volume ☐ Mass / area ☐ Volume/mass ☐ Area/Mass ☐
2. Water exists as:
   Solid ☐ Liquid ☐ Gas ☐ All above ☐
3. For flow of electric current, a circuit has to be:
   Open ☐ Closed ☐ Connected to switch ☐ Static ☐
4. Which metals react to water?
   All metals ☐ Noble metals ☐ Most metals ☐ No metal ☐
5. Water containing salt is:
   Denser than normal water ☐ Lighter than normal water ☐
   Density not affected by adding salt ☐ None of the above ☐

Sample of Post Test

1. Metals get corroded due to:
   Moisture and air ☐ Heat ☐ Low temperature ☐ Atmospheric gases ☐

2. Water floats on sand because:
   Sand is denser than water ☐ Sand is lighter than water ☐
   Density does not affect floating ☐ Both have same density ☐
3. Copper wire is covered with a plastic coating to prevent:

Electric shock ☐ High cost ☐ Corrosion ☐ Heating ☐

4. Clothes dry faster on a day that is:
   Sunny and windy ☐ Cloudy day ☐ Rainy and windy ☐ Rainy ☐
5. Which of the following evaporates the fastest?
   Petrol ☐ Cooking oil ☐ Water ☐ Milk ☐

Acknowledgments

One of us (LPSK) gratefully acknowledges discussions with Dr. H. S. Vashistha of DPS Faridabad and Mrs. Anita Sharma, currently Block Education Officer, Ballabgarh, District Faridabad, Government of Haryana. The authors acknowledge partial support for this study by Block Education Office - Ballabgarh. The authors would also like to acknowledge the cooperation of Mrs. Anita Sharma for piloting and testing this methodology in schools situated in Block Ballabgarh.

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TEACHING FRACTIONS WITH MEANING: MOVING BEYOND THE PART-WHOLE INTERPRETATION

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This paper presents examples from teaching of fractions of a primary mathematics teacher who participated in a two year long professional development program and tried incorporating new practices in her classroom while collaborating with the researcher for teaching fractions. The analysis of how tasks are implemented in the classroom revealed the challenges that arose for the teacher in implementing the intended changes and how there were shifts in the way teacher asked questions, evaluated students and gave explanations. Teacher shifted her practice from use of a deprecated version of part-whole meaning of fraction to other representations and meanings. The findings indicate how the knowledge of representations and meanings as a part of mathematical knowledge for teaching (MKT) helps a teacher change her practice towards developing understanding of fractions.

Introduction

The process of 'teacher change' has been the topic of extensive study for decades in several educational reform contexts. However, we know little about the process of change as it happens in the classroom during teaching and the factors that influence the change. Sowder (2007, p.97) emphasized that change is a "process rather than an event, it must be considered in terms of continuous growth over time". Viewing change as a "process" requires research which throws light on teachers' learning-in-practice (Adler et al, 2005; Even & Ball, 2009) on the one hand and on the other hand studies are required that illustrate the process by which teachers' learn by implementing reform-based tasks. Studies researching teacher change in context of curricular reform have found that when teachers change their orientation towards their practice, it leads to unexpected challenges like responding to novel student responses and their misconceptions. However, engaging with these challenges can be supported by the development of subject matter knowledge as well as pedagogical content knowledge to address student thinking (Davis, 1997; Sherin, 2002; Doerr & English, 2006).

In this paper, we present examples from the teaching of fractions of a primary teacher Nupur (pseudonym) while she used different representations to explore the meaning of fractions with students. The specific research questions that guided the study and analysis of data are:

1. What are the meanings and representations for teaching fractions that are prominent in the teachers' practice?
2. In what way does the teachers' knowledge about the meanings and representations of fractions

influenced the selection of tasks and their implementation?

3. What were the major changes that took place during the course of collaboration in the teacher's knowledge of meanings of fractions and how it influenced teacher's practice?

Ball et al (2008) have elaborated on how generating representations is a part of mathematical knowledge for teaching (MKT) that helps in sense making by unpacking the mathematics. Building on Ball's notion of specialized content knowledge (SCK), Kumar et al (2015) have argued that the variety of *meanings* (of integers) used in different contexts can serve as foundation for developing SCK which included the knowledge of representations and helps in establishing connections between representations and contexts. In this paper, the argument is extended to show how meaning of fractions and contexts where they are used is a form of SCK which is essential for supporting meaning making in classroom. This is reflected in the way the tasks are constructed and tasks are implemented during teaching. The analysis of teacher's practice revealed that the teacher's specialized knowledge of fraction representations and meanings shaped the way the teacher selected the tasks and managed the interactions during the discussion of the task. I claim that the nature of challenges faced by the teacher were due to limited knowledge of fraction sub-constructs which constitute SCK for teaching fractions.

Theoretical framework

To analyse the teaching of fractions the framework of fraction sub-constructs (Kieren, 1988) have been used since it illuminates about the different meanings and contexts that help to develop a holistic understanding of fractions. Kieren (1988) identified five sub-constructs of fractions namely part-whole, share, measure, operator and ratio which can be illustrated in different contexts and representations and are described below. The sub-construct theory is based on an assumption that sub-constructs are the various meanings of fractions within different contexts and thus different contexts may denote different sub-constructs. Although, they do not directly correspond to the real world, they are helpful in making sense of the situation by using different meanings of fractions. He argued that children develop an impoverished concept of fractions as a result of being exposed to only those contexts and representations which exclusively use the part-whole meaning of fractions.

The part-whole meaning which is the most commonly used interpretation, is often denoted with an area representation by shading equal parts of a whole. Here, the fractions are named based on the number of equal parts of the whole. The measure interpretation is most often using in the contexts of measuring quantities and where the units are divided into subunits to denote the exact amount of the quantity more precisely. e.g. 2 ½ km, 5 ¼ litres of petrol etc. When a fraction a/b is interpreted as the share that one gets by dividing a quantity 'a' into 'b' number of equal shares, it is a quotient interpretation. The operator meaning corresponds to the multiplication by a factor and denotes taking a multiple or factor times a certain quantity, for e.g. 2 ½ times the amount of rice or ¾ of 12 hours denotes to fraction of a certain quantity e.g. when one is referring to the quantity consumed ('½ of the potatoes are left') or the amount of time that has passed in a certain period (¾ of the science period is over) or to refer to the part of a population ('¼ of the teachers tried teaching fractions using a context'). The ratio interpretation, involves the relation between the numerator and denominator of the fraction which denote two different quantities which may or may not have the same measure (For more discussion, see Subramaniam, 2013).

The study

The findings being reported here are part of a larger study from 2009-2011 on collaborating with teachers to develop classroom practices aimed at teaching mathematics for understanding. The study had different components: professional development workshops, collaborative follow-up of classroom teaching by the researcher and planning and designing instruction for specific topics. Participants in the larger study were 13 mathematics teachers (5 primary and 8 middle) in a nation-wide Government school system and were nominated by their principals to participate in the study. In this paper, data from one primary teacher's (Nupur) classroom teaching from the collaborative phase post the workshop has been reported.

Case studies have been found useful in constructing explanations about the phenomena observed through the process of detailed data collection and participant observation of the subject to know the meaning held by them. Thus, the case study approach was adopted wherein detailed data in form of field notes, audio records and logs of classroom teaching was collected during the phase of collaboration with the teacher Nupur. The researcher visited Nupur's classroom in two time periods: Aug 2009 and July-Aug 2010. A total of 39 lessons of 35 minutes each were observed (15 and 24 respectively in each period). In this paper we present an analysis of Nupur's teaching of equivalent fractions which the researcher observed for 10 lessons in first year and 4 in the second year. Informed consent of the teacher was taken for collecting and using the data records for research and educational purpose. At first day-wise description of teaching and discussions with the teacher was constructed using the field notes of the researcher, logs of the classroom and notes about the discussion with the teacher after some of the classes. Audio records were reviewed to annotate and add relevant transcripts. The classroom interactions were analyzed to understand what representations and sub-constructs were used to guide the selection of tasks and their implementation in the classroom and to identify the challenges that she faced in implementation.

At the time of the study (2009), Nupur was 46 year old, held a M.Sc. degree in Chemistry and a B.Ed degree and had been teaching maths and science at primary level for 21 years. She appreciated the need for developing reasoning behind mathematics and talked about the need to connect mathematics with daily life and focusing on concepts rather than rote memorization of procedures. Among the participants in the study she was judged to be most likely to appreciate a conceptual focus in teaching and was hence chosen for the case study. During the period of observation she was the class teacher of grade 5 consisting of 45 students. Majority of the students in her class belonged to the lower middle class group.

Findings

Analysis of the tasks that were used by the teacher for teaching revealed that Nupur shifted from using a perception-based deprecated part-whole meaning of fractions to meaningfully connecting the measurement and part-whole meaning of fraction using visual representations. While implementing the tasks, the nature of questions changed from closed leading questions to the questions asking students to explain how they got the answer. She encouraged students to evaluate the answers of their peers and to use visual representations and their spontaneous strategies rather than mechanically using procedures to find the correct answers. There were changes in the way she questioned, explained the concept and evaluated the students as the teaching progressed as she incorporated other meanings of fractions in her repertoire. We present examples from her teaching on fractions to provide evidence for the claims made.

In the first lesson that the researcher observed, Nupur was teaching equivalent fractions using an area model, with the circle as a unit. The approach involved making equal divisions of a circle and coloring some of them. Through a set of leading questions, she first established that in the fraction notation one should write the number of shaded (colored) parts upon total (equal) parts. Student responses of the type "2 green parts and total 8 parts" were taken as correct reasons for saying why a colored part was denoted as 2/8. Then she made circles having 2, 4 and 8 parts and asked students to shade some parts so that it resembled a "half moon". Her emphasis was on highlighting the perceptual similarity between ½ and equivalent fractions of ½. After a few examples of drawing and shading fractions equivalent to ½, she pointed out that "denominator is double of numerator". She asked students to give equivalent fractions of ½ without the use of a picture and listed answers on the blackboard. After this whole class teaching, she assigned individual work asking students to make a drawing of ½ and an equivalent fraction. Nupur moved among the students checking if they had made equal parts and if the equivalent fraction looked like ½. For example, she told one student "your answer is wrong since it is not matching with ½". Here the sub-construct used is a deprecated version form of part-whole since the shape of the part is being focused rather than the relation between part and whole. Referring to the count of parts to denote numerator and denominator by double counting also treats the fraction as being made of two whole numbers rather than being a single number denoting a quantity. This can lead to misconceptions e.g. naming fractions by writing shaded/unshaded parts.

During the lesson, the researcher spoke to students and realized that some of them thought that "4/8 cannot be written as ½." This is because students were focusing on the differences in terms of number of parts rather than focusing on the equivalence of area denoted by the fractions. Thus, deprecated part-whole meaning created a misconception for students. This misconception became further clear when Nupur invited the researcher to ask the students some questions and she asked if 2/4 was the same as ½. Following the negative response by students, she asked students to think about a situation when someone ate two ¼ pieces of a cup cake and whether it would be the same as eating half a cup cake. Some children seemed unconvinced about 2/4 and ½ being the same. One student "corrected" a picture of 2/4 of a circle by erasing the dividing line and said, "Now it is half".

The researcher asked the students to think about the question as homework by visualizing ½ a cup cake and the two ¼ pieces on the two sides of a balance. Here the researcher has used measure sub-construct to denote the size of the part and equivalence between parts that are same in size while the limitation of the idea of focusing on the shape of the part for denoting the fraction became clear to both student and the teacher. Following this exchange, Nupur said to the researcher "it means that student do not understand through numbers... they have to do it with some object... we can try by making pieces of a paper rectangle". Although Nupur had initially thought that the students understood equivalent fractions based on her questions, she now thought that the researcher had identified "students' confusion" which she had not "stressed" in her teaching. Through this exchange, she was confronted with the challenge of adequately assessing students' understanding.

In the period of collaboration, Nupur moved from a perceptual focus for teaching equivalent fractions to realizing that always focusing on particular prototypical figures for fractions having continuous shaded areas amounts to "rote memorization". She attempted to move away from prototypical visual forms for fractions while using fraction strips by asking students to denote the fraction for shaded parts that were disconnected. In the second year, she encouraged a discussion in her class of a task where students moved to understanding that the shaded parts can be arranged in different ways and still the fraction would remain the same. She also realized how emphasizing on counting of parts lead to problem in understanding fractions, an insight that she shared in a meeting with other teachers of the school.

Nupur also struggled with the operator meaning of fraction and how to make student understand the fraction of a quantity. The textbook had a problem which required students to find out 2/5 of the 100 slaps that one of the gatekeepers will get, in a context of an Akbar Birbal story. She asked students to share their answers and then explain their answers. She found that even students who were able to give correct answers were not able to explain and showed only the procedure of how to multiply 2/5 with 100. A student even got the correct answer using a completely wrong procedure of meaningless cancellation and multiplication to get the correct answer. In attempting to give an explanation which made sense, Nupur hinted students to identify the pattern by stating that 2 "out of" 5 is same as 4 "out of"10 and then asked them to guess what should be numerator when the denominator has 100 for it to be same as 2/5. Some students were able to give the correct answer. Since majority had not understood she proceeded to circle every 2 dots out of 5 dots made on the board up to 100 dots and then stating the answer as 40/100.

In this event, the textbook problem foregrounds the operator meaning of fraction by asking student to find fraction of a quantity i.e. 2/5 of 100. However, the teacher tried to establish the equivalence between 2/5 and 40/100 by using the deprecated part-whole meaning where fraction represents x parts out of y parts rather than x equal parts of the whole of the size 1/y. Here 'x' and 'y' are treated as whole numbers and the fraction is interpreted as a ratio of two quantities rather than using operator meaning of a fraction of a quantity. While the situation can be interpreted using different meanings of fractions including ratio, the avoidance of operator meaning in this case limits students' understanding that an amount can be equal to 2/5 of a quantity. A possible explanation of the impasse that occurred while teaching is that the teacher was not able to use the appropriate meaning in this context to build on students' understanding of fraction.

After the discussion with the researcher about students' misconceptions regarding fractions and a discussion about the importance of using the idea of unit fractions and composite fractions in understanding equivalent fraction, she decided to work with a linear model for representing fractions: fraction strips i.e. paper strips of equal size, which are folded to show parts. The fractions strips afforded a new way of checking for equivalent fractions – by juxtaposing fraction strips and focusing on the size of parts denoting their area, which the students used to explain and justify their answers. After working with fractions strips, students were able to estimate the size of an indicated part, even when equal partitioning of the strip was not done. e.g. Using the figure given below and with some help by the teacher, students were able to use the fraction strips to argue that 12/16 would be equal to 3/4 since parts representing 12/16 are of the same size as 3/4 of a whole. While discussing, the teacher did not move on after getting the correct answer from students but asked the students to give explanations using fractions strips and fraction chart shown in Figure 1 below.

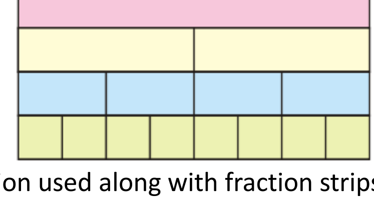

Figure 1: Representation used along with fraction strips to discuss 3/4 and 12/16

Here students are using the measure meaning of fractions to argue about the equal size of two fractions rather than based on number of parts. In making this argument, the students were able to reason that each part in fraction strip representing 12/16 is of 1/16 size and when one considers altogether 12 parts of this size, it represents 12/16. In later lessons, the teacher became careful that students understand that equal parts of an area can be made in different ways and gave tasks in which contiguous or noncontiguous parts can still denote the same composite fraction.

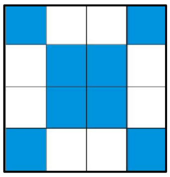

Figure 2: Task to name the fraction with non-contiguous parts

A student reasoned that the figure can be represented by 8/16 as well as by 2/4 by showing how the smaller 4 equal parts of size 1/16 combine together to form parts of size 1/4.

Nupur became sensitive to the misconceptions among students and tried addressing them in her teaching by giving tasks e.g. to address students misconception of reversing numerator and denominator while naming fractions, she asked students to visualize and find the difference between 8, 1 and 1/8 as students frequently used to say 8 when they meant 1/8. She took up an activity using papers to describe the difference and students were able to understand that 1/8 is just one part of the whole paper which has been divided into 8 parts. Here teacher is trying to establish the relationship between the part and the whole and is using part-whole meaning of the fraction. She also showed how the parts 1/8 when iterated 8 times completely measure the whole, thus using the measure meaning. As her teaching progressed, she was sensitive to student's use of "whole number language" about parts realizing it as a conceptual issue. Nupur realized the value of using representations as tools for sense making although she was not able to use them to unpack the procedures used for finding equivalent fractions.

Discussion

The examples given in this article, illustrate how teachers' knowledge of fractions meanings and representations influenced the way she used the task in classroom to develop students' understanding. It also illustrates how the change in this knowledge as a result of collaboration with the researcher, bring about the change in the meanings and representations used along with practices of asking questions, explanations and evaluation. To sustain the change in practices the most important support identified is the development of teachers' knowledge regarding knowing how to act in situations which may be unanticipated as well as knowing the content in flexible ways to link with students' understanding. This knowledge helps the teacher to pursue the classroom discussion beyond just establishing the answer as right or wrong, pursuing students' conjectures and responses to develop important mathematical concepts allowing her to build explanations based on students' responses and above all basing the teaching on students' thinking rather than what is given in the textbook.

An important part of this knowledge is the knowledge of different sub-constructs of fractions since it helps teachers to make decisions about what tasks to pose and how to develop meaning during task implementation. For teaching to be determined by the student's thinking, a teacher has to be empowered to take decisions like selecting appropriate examples for teaching, recognizing opportunities from student's responses to develop important concepts, constructing questions for assessment of understanding and also determining which responses of students should and should not be considered as indications of understanding.

The analysis of Nupur's practice calls into question the studies which view change in beliefs as an endpoint and emphasize that much remains to be learnt for the teachers in order to turn their "explicit beliefs" into "enacted beliefs" (Even and Ball 2009). It also raises the question of what should be counted as change in beliefs- the explicit articulation of the teacher or change in classroom practices. It emphasizes the need for identification of challenges that arise for teachers when they try to make changes in their routines and designing of ways to support teachers to overcome those challenges.

The study has implications for designing professional development and viewing teachers' learning-in-practice that happens through adoption of new practices with the purpose of developing conceptual understanding in students. The challenges posed by such a situation for teachers needs to be dealt with in order to sustain the change in the practices. Presence of collaborator is one such way to overcome the challenges by utilizing resources of the collaborator in terms of her knowledge, sensitivity and source of challenge by providing alternative viewpoints.

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A STUDY ON UNDERSTANDING HOW TEACHERS OVERCOME CHALLENGES OF ACTIVITY BASED SCIENCE TEACHING IN GOVERNMENT SCHOOL OF SHEOGANJ BLOCK (SIROHI), RAJASTHAN

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This study is an effort to understand the ground realities of the activity based science teaching in the government schools of Sheoganj block of Rajasthan. Activity based learning in science is essential for developing scientific skills and scientific temper; it provides children the opportunities to construct their own understanding and makes learning joyful. Objectives of science teaching are not fulfilled until scientific skills are developed in children (National Curriculum Framework (NCF) 2005 and Right to Education (RTE) ,2009. This study is an effort to find the challenges faced by science teachers who use activities in their classrooms and also understand how they overcome some of these challenges. The sample of teachers involved in the current study is 8 and we have used pre-/post-activity discussion and classroom observation. The work reveals that often teachers try to do the activities with which they are familiar and confident and thus, the objective of using activities for development of scientific skills is not fulfilled well. Also the challenges faced by teachers with non-science background are higher as compared to those with science background.

Introduction

As we are working for the teacher professional development, it is necessary to understand the challenges faced by science teachers who use activities for teaching science. It is equally important to understand whether these activities are fruitful for children and while using such practice, do teachers focus either on science learning or processes of science. The current study is aimed at developing a feel for problems faced by teachers who are teaching science with activities and how they are dealt with. The observations of the study have significant implications for teacher professional development programmes.

Literature review

In the activity based teaching, the major responsibility of teachers is to provide children suitable environment for doing activities given in the available resources. Teacher must be equipped with the content knowledge and skills of implementing activity in the classroom (Mishra & Yadav, 2013) for fruitful implementation of activities. With the activity based approach, curiosity of children increases, children passes through the process of thinking and it is necessary to construct knowledge. In doing experiments, time management is one of the challenges (Akhtar, M. H. & Husain M., 2013).

Research questions and methodology

To study challenges in activity based science teaching classrooms from following perspectives:

1. type of challenges faced by teachers
2. those dealt successfully by teachers and the ways by which the same was achieved
3. those could not be dealt successfully by teachers
   (Problem may be in the content knowledge, process, time management, resources, using of resources, motivation etc.)

The research study will be done with the government teachers of the Sheoganj block of Sirohi district of Rajasthan. The teachers were identified by schools visits and through our interactions and observation during workshops and forum such as SSA trainings conducted by the researcher and his colleague. They were engaged with us for a significant amount of time and were teaching the classroom with activities .

Discussion guidelines used with teachers involved following questions- a) What is the activity and the topic for which it is used? b) Have you introduced the topic prior to the activity? and c) Are there enough resources for the conduct of the activity?

During the classroom observations of teachers, efforts were made to assess following points- a) initial interactions with children, b) creating environment for the activity, c) ways of instruction about the activity, d) efforts to involve every child in the activity, e) providing appropriate resources, f) guiding children towards the concept and g) explaining the activity with appropriate concept

The discussion conducted with teachers in post class room observation were related to a) teachers opinion about activity done in the classroom, b) types of challenges faced, c) challenges faced for engaging every child, d) how they tackled these challenges, and e) the challenges that are still to overcome, and the appropriate ways to do so.

Eight teachers, containing equal number of teachers with science and non-science background, teaching science in upper Primary schools of Sheoganj Block were selected for the study. The study involved conceptualisation phase and the actual field work with documentation. The overall duration was about five months.

Data analysis and major observations

Data collected from the interactions, interviews and classroom observations was analysed with respect to situation, resources, training and motivation of teachers and the challenges which are difficult for teachers to overcome. Analysis will be done on the basis of-

One of the difficulties faced by teachers was related to time as most of the activities are not doable in thirty minutes. For activities spread over 2 or 3 days, e.g. germination of seed or sky related activities, only few children could perform activities at home. Such activities involved writing of observations which was another major concern as students were not proficient with writing. As the text book presented many activities and as the syllabus had to be completed for examination, teachers focused on completing the activities rather than looking at the conceptual understanding.

Ensuring participation of all children and assessment about their understanding of the concept for which activity is facilitated within the stipulated time is the major challenge.

The above difficulties were profound for non science teachers as with less/no understanding about the content, they required more time to guide children according to their need while performing the activity.

Science kit has been provided in a school that contains necessary equipment for activities given in the book. Resources given in the science kit are limited and thus could not be arranged for the entire class. Due to resource crunch, the participation all the children is difficult in the activity is an issue. It is difficult to provide hands on experience to every child and thus, many children lose interest and thus, get indulged with some other work. Chemicals provided in the science kit are spoiled and thus experiments that use these chemicals are often not done.

Relating the concepts to the content of the activity is a challenge, especially for non-science teachers. Often these teachers who studied science till class X lack of conceptual understanding. Balancing between the concept, content and activity is an issue. These teachers lack in understanding of the technical words/terminology given in science textbooks which affect their explanation of activity. The problems are more serious for chemistry content. Often, the process part of activities, described in the textbook remains neglected as teachers have to deal content of the activities. In other words, all teachers (science/non-science background), are unable to realize the importance of why activities should be done by children. They often hastily perform the activities on their own and try to present the conclusion and concept associated with activities. Thus, children become mere observers for activities.

How do teachers handle some of the above mentioned challenges

In some cases, it was observed that some of the teachers manage resources from their own home or ask children to bring the same. They ensure hands on experience for every child.

To manage time, teachers did those activities in the classroom about which they were confident both w.r.t. actual conduct and time management. The hands on experience of activities which teachers can learn in the workshops related to activity based science teaching is thus important as it gives confidence to teachers to handle the same in the classroom. As in such cases, teacher managed to finish the activity in the given time and thus, s/he spent time for dealing with children's understanding. Teachers used questions related to the activities at hand for assessing children' s understanding which then follows explanation.

For long duration activities, the same was arranged in the school. Teachers asked children to note down the main points for the part of the activity performed per day. Thus, all children observed the activity regularly and the risk of any child not doing activity at home is taken care off. Students are then guided to the conclusions and understanding of concepts related to the activities (This is main aim for presenting such activities in the textbook).

Science background teachers interacted with non-science background teachers in their own school for the preparation of activity. If necessary, science background teachers engaged these teachers while performing activities in their classroom. This type of practice help was important for non-science background teacher to overcome the difficulties of using resources and facilitating children towards the concepts. In some schools, non-science background teachers took help from the other school teachers, especially from the teachers teaching science at secondary level. Such conversations involved discussions about the apparatus required for activity and its handling. Chemicals needed were also arranged, sometimes from other schools. Thus, peer networking plays a significant role in building the confidence of teachers.

Inference & Implications

The study highlighted various points. Teachers are willing to conduct the activities; however they do need help regarding the challenges faced by them. Often, hands on experiences make teachers confident and comfortable in conducting the activities in the classroom. Such experiences may exist with science background teachers but are needed for the non-science background teachers. The same has to be an integral part of the workshop/training programmes conducted for teachers. Peer interaction between these two groups of teachers also help to develop the same among the non science teachers.

Time management is an issue and thus, long activities are generally avoided by teachers. However, the same can be achieved through self-motivation and own efforts as can be seen in the discussion presented in the paper. Teachers did mention engagement in administrative works at the school often takes away the time needed for self-preparation for the activities and conduct of all activities given in the textbooks. During classroom observation, it was observed that few teachers use the difficult/technical terms while explaining the concept. It is important that teachers make proactive efforts not to use such words and also check students' familiarity with such words.

Use of alternative activities, managing resources from easily available everyday items and knowledge of the equipments help teachers, especially non-science teachers, in conducting these activities. Thus, it is crucial that all these aspects should further become central to teacher training workshops. For activities, where the concept need to emerge through actual conduct of activity, content and concept discussion in a simpler language needs to conducted for teachers. Such a support along with hands on experience about the activity is needed for teachers, particularly non science teachers who themselves will develop better understanding of the concept.

Acknowledgements

I am thankful to Azim Premji Foundation for providing me an opportunity of ground level study, I also thank Tirang Rangsaranemei, Amol Kate and Narendra for continuous support during the whole process of the study.

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DID MOBILE APP-SUPPORTED MATH TRAILS INCREASE THE STUDENTS' MOTIVATION?

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The MathCityMap-Project was developed by combining the concept of a math trail program with advanced mobile technology. It aims at providing a new approach to promote student motivation to engage in meaningful mathematical activity. An exploratory study was conducted as a pilot using nine secondary schools in the city of Semarang, in Indonesia, and 272 students and nine teachers were included. Using self-determination theory as a framework, we explored the motivation of students to engage in mobile app-supported math trail activity. Data collection procedures comprised observation, interviews, questionnaires, and student work analyses. Findings indicate that intrinsic motivation and identified regulation established an essential part of students' motivation to engage in this activity. The design of the learning environment, the use of mobile app, and the value of the mathematical task have contributed to this result.

Introduction

A math trail, a path for discovering mathematics, was created as a medium for experiencing mathematics in all its characteristics, namely, communication, connections, reasoning, and problem solving (Shoaf et al, 2004). In such a trail, students can simultaneously solve mathematical problems encountered along the path, make connections, communicate ideas and discuss them with their teammates, and use their reasoning and problem-solving skills. Although the math trail project is not new, supporting this outdoor education with mobile technology is an innovative approach to the program. This idea appears together with the fact that, in recent years, mobile technology has significantly improved and mobile phone use has significantly increased (Lankshear & Knobel, 2006). These advancements have been followed by the creation of many mobile phone applications (apps), including those intended for use in outdoor activities. In learning activities, Wijers et al (2010) suggested that mobile devices could be employed to facilitate learning outside the classroom. They also suggested that mobile technology could be exploited to support the outdoor educational program. Integrating advanced technology with the math trail program is the basis for the development of our project, called the MathCityMap-Project, in which math trails are facilitated by the use of GPS-enabled mobile phone technology. This project has been developed and implemented in Indonesia since 2013 and has been tailored to this country's situation. The main focus of this paper is to explore the motivation of students to engage in a math trail program supported by the use of a mobile app.

Theoretical background

The MathCityMap-Project (www.mathcitymap.eu) is a project of the math trail program, which is supported by the use of a GPS-enabled mobile phone app and uses specialized mathematical outdoor tasks (Jesberg & Ludwig, 2012). This project was not conceived merely to design and/or use the math trails. Instead, it includes the entire process: preparation (how to design it), implementation (how it runs), and evaluation (how it impacts student motivation). The mobile phone app (available on Google Play Store and Apple Appstore), as a supporting tool, was also created and used during this project. Therefore, the theoretical framework for the MathCityMap-Project study is underpinned by the concept of the math trail program, the use of mobile technology in mathematics education, and student motivation in mathematics.

A math trail is a walk in which mathematics is explored in the environment by following a planned route and solving mathematical outdoor tasks related to what is encountered along the path (English et al, 2010). In math trail activities, "children use mathematics concepts they learned in the classroom and discover the varied uses of mathematics in everyday life" (Richardson, 2004, p. 8). They discover real problems related to mathematics in the environment and also gain experience connecting mathematics with other subjects. Among the many benefits of a math trail (Richardson, 2004) is the creation of an atmosphere of adventure and exploration resulting from the fact that it is located outside the classroom. A math trail guide, such as math trail map or human guide, must be prepared to inform walkers about the math trail task stops and to show the problems that exist at each location. It also tells about the tools needed to solve the problems, so that the walkers are prepared before starting to walk on a trail. With the rapid development of technology nowadays, it is possible to collect the tasks and design a math trail guide based on a digital map and database.

In recent years, rapid developments in technology have occurred in the scope, uses, and convergence of mobile devices (Lankshear & Knobel, 2006). These devices are used for computing, communications, and information. Mobile devices are portable and, usually, easily connected to the Internet from almost anywhere. This makes them ideal for storing reference materials and learning experiences, and they can be general-use tools for fieldwork (Tuomi & Multisilta, 2010). Their portability and wireless nature allow them to extend the learning environment beyond the classroom into authentic and appropriate contexts (Naismith et al, 2004). Wireless technology provides the opportunity for expansion beyond the classroom and extends the duration of the school day so that teachers can gain flexibility in how they use precious classroom activities. The use of mobile devices can also promote positive emotions for students toward learning mathematics (Daher, 2011). These advantages have been exploited through the MathCityMap-Project. Math trail blazers can create and upload math trails into a database through a web portal, then the math trail walkers can access them and complete the math trail with the help of a GPS-enabled mobile app (Cahyono & Ludwig, 2014; Jesberg & Ludwig, 2012).

In this paper, we focus on the exploration of the factors that motivate students to engage in mobile app-supported math trail activity. The academic literature distinguishes between two motivational concepts namely: extrinsic motivation and intrinsic motivation. An influential theory that explicates intrinsic–extrinsic motivation in depth is self-determination theory (SDT, Deci & Ryan, 1985). The SDT model conceptualizes a range of regulation from intrinsic motivation to amotivation. Between these, there exist identified regulation and external regulation. Intrinsic motivation exists when a student is engaged in an activity for his/her own sake/pleasure/satisfaction. Identified regulation refers to engagement that is valued as being chosen by oneself. External regulation is the type of motivation when engagement is regulated by rewards or as a way to avoid negative consequences. Lastly, amotivation is associated with engagement that is neither intrinsically nor extrinsically motivated (Guay et al, 2000).

Having outlined the theoretical background for this study, we can clarify the research question: *what is the nature of student motivation to engage in a math trail program supported by the use of a mobile app?*

Methods

An exploratory study was conducted in the city of Semarang in Indonesia involving nine secondary schools. The participating schools represent three levels (high, medium, and low) and two location types (downtown and suburban). The involved students were between 14 and 15 years old. Indonesia by itself performed very low in mathematical literacy during the last PISA Studies. This study is a part of development research on the MathCityMap-Project for Indonesia. There were two main phases in this research, namely the design phase and the field experimentation phase. Here, we focused on studying student motivation to engage in the activity that was conducted in the second phase. This phase consisted of an introduction session, a treatment (math trails guided by the app), and a debriefing session. Student motivation was measured using the self-reported Situational Motivation Scale (SIMS) developed and validated by Guay et al (2000) based on self-determination theory (SDT). The results of their study exposed that the SIMS represents a brief and adaptable self-report measure of situational intrinsic motivation, identified regulation, external regulation, and amotivation. ‘Situational motivation’ refers to the motivation individuals experience when they are currently engaging in an activity (Guay et al, 2000). Therefore, this questionnaire is appropriate to be employed in this project to explore motivation of student to engage in the activity.

The SIMS is a 16-item questionnaire consisting of 4 subscales, intrinsic motivation (IM), identified regulation (IR), external regulation (ER), and amotivation (AM). In the first part of the instrument, the questionnaire asks, ‘Why are you currently engaged in this activity?’ Respondents are to rate a number of answers using a 7-point Likert scale from 1 (*not at all in agreement*) to 7 (*completely in agreement*) for each item. The items are: ‘because I think that this activity is interesting’ (IM), ‘I am doing it for my own good’ (IR), ‘because I am supposed to do it’ (ER), ‘there may be good reasons to do this activity, but personally, I don’t see any’ (AM), ‘because I think this activity is pleasant’ (IM), ‘because I think this activity is good for me’ (IR), ‘because it is something that I have to do’ (ER), ‘I do this activity, but I am not sure if it is worth it’ (AM), ‘because this activity is fun’ (IM),‘it was my personal decision’ (IR), ‘because I don’t have any choice’ (ER), ‘I don’t know; I don’t see what this activity brings me’ (AM), ‘because I feel good when doing this activity’ (IM), ‘because I believe that this activity is important for me’ (IR), ‘because I feel I have to do it’ (ER), and ‘I do this activity, but I am not sure it is a good thing to pursuit it’ (AM).

The four subscale scores are then used to calculate a single motivation score called the Self-Determination Index (SDI) for each student using the following formula: SDI = (2 x IM) + IR – ER – (2 x AM) (Sinelnikov et al, 2007). The SDI score ranges between (2 x 1) + 1 – 7 - (2 x 7) = -18 and (2 x 7) + 7 – 1 - (2 x 1) = 18. A higher SDI score indicates that the student is more self-determined and more intrinsically motivated to engage in the activity. A positive SDI score indicates that, overall, more self-determined forms of motivational type (IM & IR) are predominant (Vallerand & Ratelle, 2002). Then, open-ended follow-up questions were given to students to deepen the information about deciding factors affecting student engagement in this mathematical activity. Data were analysed using qualitative methods to discover whether and what kind of motivations influenced these students. Quantitative data were also collected and analysed. Non-parametric statistical calculations were performed because the data consisted of ordinal scores, and normality could not be assumed.

Results & Discussion

In the first phase of the MathCityMap-Project study in Indonesia, technical implementation of the project was formulated, and a mobile app was also created to support the program (Cahyono & Ludwig, 2014). Thirteen math trails containing 87 mathematical outdoor tasks were also designed around the city of Semarang (Cahyono et al, 2015). Task authors found mathematical problems that involved objects or situations at particular places around the city. They then created tasks related to the problems and uploaded them to a portal (www.mathcitymap.eu). In this portal, the tasks were also pinned on a digital map and were saved in the database. Each task contained a question, brief information about the object, the tools needed to solve the problem, hint(s) if needed, and feedback on answers given. Math trail routes can be designed by connecting a few tasks (6-8) in consideration of the topic, level, or location. In designing the trails, it is also necessary to consider several factors such as: safety, comfort, duration, distance, and accessibility for teachers who would observe and supervise all student activity.

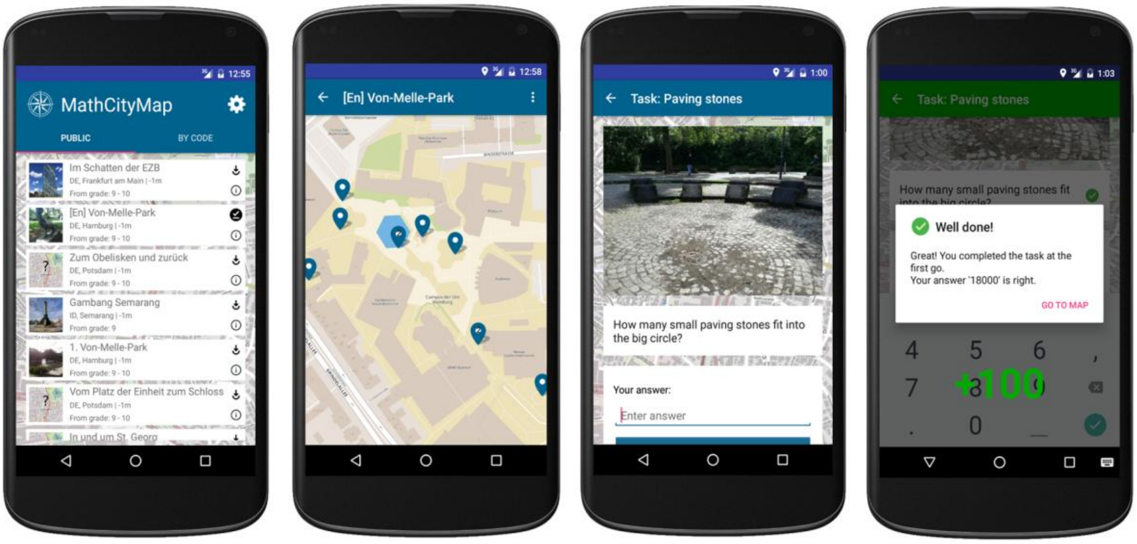

Figure 1: App interfaces (Map: ©OpenStreetMap contributors)

Figure 1 shows examples of the app's interfaces including an example route, task, feedback, and hint. Math trail routes can be accessed by students via the mobile app, a native app that was created by the research team as part of this project. Installation of a file in *.apk format was uploaded to the portal as well as the Google PlayStore™ and Apple Appstore. From there, students could download and install the app, which works offline. Students can then carry out math trail activities with the help of the app. They follow a planned route, discover task locations, and answer task questions related to their encounters at site, then move on to subsequent tasks. The app informs them of the tools needed to solve the problems, the approximate length of the trail, and the estimated duration of the journey. On the trail, the app, supported by GPS coordinates, aids the users in finding the locations. Once on site, users can access the task, enter the answer, get the feedback, and ask for hints if needed.

In the second phase, field experiments were conducted with 272 students and nine mathematics teachers. Each school was represented by a class consisting of an average of 30 students. They were divided into groups of five to six members. Four schools carried out activities outside the school while five schools conducted activities in the school area. These choices were made because of conditions and situations (such as: safety and availability of teaching and learning time) unique to each school. The activities were conducted during normal school hours over two 45-minute periods beginning with the teachers giving a brief explanation of the learning activities and goals. Groups then began their journeys, each from a task location that was different from the others (Group I started at task I, Group II from task II, and so on). As the groups trekked the trail, teachers observed and supervised student activities but were not expected to provide assistance because all the necessary information was to be provided by the app. Once the activity was completed or maximum time allowed for the activity had passed, the students moved to the next task. After completing the trail, each group returned to class, then had a discussion with the teacher about the task solutions and what they learned along the trail. At this time the questionnaire was also completed by the students. All 272 students' SIMS responses and SDI scores are summarized in Table 1.

	IM	**IR**	**ER**	**AM**	**SDI**
N	272	272	272	272	272
MIN	3.50	2.25	1.00	1.00	2.00
MAX	7.00	7.00	6.25	5.50	16.25
AVERAGE	5.9770	4.7215	3.4651	2.9779	7.3180
SD	0.82939	1.23314	0.93080	0.91471	2.92629

Table 1: Students' SIMS and SDI scores

Averages SIMS scores for the four subscales varied considerably, ranging from 1.00 to 7.00. The standard deviations indicated adequate variability in all subscales. It is apparent that the nature of these students' motivations to engage in the activity is diverse. However, all had positive SDI scores (ranging from MIN = 2.00 to MAX = 16.25 and average ± SD = 7.3180 ± 2.92629). This result indicates that overall, their motivation was more self-determined. Positive scores in this case indicate that internalized forms of motivation, namely intrinsic motivation and identified regulation, were predominant. Students perceived the activity to be interesting or enjoyable (an indicator of IM) and meaningful or valuable (an indicator of IR). They were engaged in the activities for their own sake/pleasure/satisfaction, and their engagement was considered to be a self-choice. This finding is supported by the Independent-Samples Kruskal-Wallis Test (Table 2), which shows that there was a statistically significant difference in score between the SIMS subscales, $\chi^2(2) = 623.583$, $p = 0.000$, with a mean rank score of 886.37 for IM, 637.52 for IR, 379.97 for ER and 274.15 for AM.

Compared with other subscales scores (Table 1), the amotivation subscale had low average SIMS scores ($AM_{average} = 2.9779 \pm 0.91471$), which were contributing factors to the positive SDI scores. These low scores indicate that students enjoyed the activity and found value in it, which was reflected in the intrinsic motivation scores ($IM_{average} = 5.9770 \pm 0.82939$) and identified regulation scores ($IR_{average} = 4.7215 \pm 1.23314$). Students also reported being motivated by and were reacting to external demand, an indicator of extrinsic regulation. However, the ER scores ($ER_{average} = 3.4651 \pm 0.93080$) show they tended to be neutral on this subscale.

	Subscale	N	Mean Rank
Score	IM	272	886.37
	IR	272	637.52
	ER	272	379.97
	AM	272	274.15

	Score
Chi-Square	623.583
df	3
Asymp. Sig.	.000

Table 2: Kruskal-Wallis Test using subscale (IM, IR, ER, AM) as the grouping variable.

The open-ended questions asked in the next step focused on two types of motivation, namely intrinsic motivation and identified regulation. The first question was, '*Why did you enjoy the activity?*' We found that 30% of the students enjoyed learning outside the classroom, 23% were excited to use the advanced technology, 18% were satisfied with applying mathematics, 16% liked collaborating, 11% reported different reasons, 2% mentioned negative feelings, and 0% did not give a reason. The second question was '*What experiences influenced your consideration that this activity was valuable?*' (Each student could mention more than one experience). Students mentioned application of mathematics in real life 158 times, outdoor mathematical activities 96 times, advanced technology for math 87 times, use of non-standard measuring tools 79 times, team work 72 times, activities in public places 65 times, and other 19 times. These answers showed that most students were delighted to engage in this activity because it was conducted outside the classroom, an unusual setting that offered comfortable conditions and it was a free and fun activity. The use of mobile devices for outdoor mathematics learning activities has become an attraction, encouraging students to engage in this activity. However, as a serious mathematical learning activity, it was not only enjoyable, but the students considered it a valuable activity. They reported that through this activity they learned how to apply mathematics in the real world, even where they had never thought about it in the past. The use of the latest technology in the learning process has also been reported as a valuable experience and new knowledge for them.

The self-reported data and answers to the follow-up questions were cross-checked with information obtained through field observations and the student works analyses. For example, here is one of the results of observations and analysis of student work on the Flood Gate Task, a task located on the Old Town Route. In this task, the problem statement is, *'Suppose your city is now in an emergency, and you are asked to raise the floodgate one meter from its original position. How many times must the worm drive be rotated to raise the sluice one meter from its original position?*'. This task is situated at one of the tourist attractions, an icon of the city, namely the Old Town area of Semarang City. All students agreed this was a pleasant place for learning math, and it was near the school where there were lots of trees, a pond, a garden, nice old buildings, and traffic was not too congested. These conditions made them feel joyful and comfortable in performing the activity there. Not only the location was exciting for them, the task was also considered by students to be a meaningful mathematical task because it was an important issue for them as citizens to know how this floodgate works. In this way, they could save their town if there were an impending disaster. Figure 2 shows an example of students working on this task.

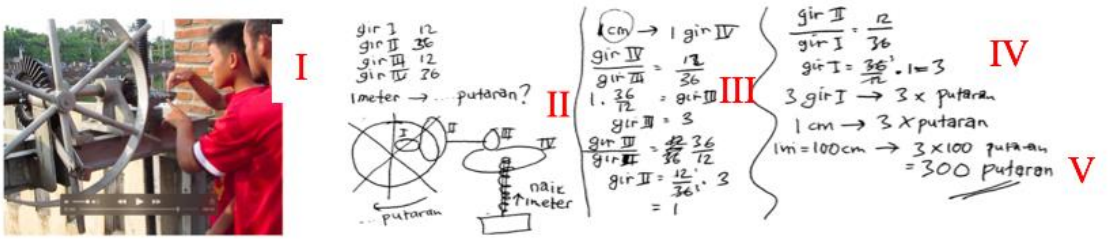

Figure 2: Students work on the flood gate task

It appears that the students had the opportunity to learn and practice ways of solving real problems by following the stages of mathematizing, namely, understanding a problem situated in reality (I), organizing the real-world problem according to mathematical concepts and identifying relevant mathematics (II), transforming the real-world problem into a mathematical problem that represents the problem situation (III), solving the mathematical problem (IV), and interpreting the mathematical solution in terms of the real situation (V). In addition, working in the environment to find the hidden task location was interesting and challenging for the students. They reported that the more hidden the task location, the more curious they were to find it. It was breathtaking for them when they had to match the coordinates of their current position and the coordinates of the task location. Here, students recognized the importance and attractiveness of utilizing a GPS-based mobile app as a navigation tool in the math trail activity. This is just one example task, and in general, the students' activities in this field experiment were similar. This explanation proves that the results of the student self-report instrument to determine their motivation to engage in activities coincided with actual conditions in the field.

Based on these findings, we conclude that the design and arrangement of the math trail and the mobile app as well as a combination of both have been successful in creating a pleasant situation and attractive environment offering valuable knowledge and experience in mathematics. They embody the aspects of enjoying or being interested in the activity and the use of advanced mobile technology for learning mathematics (an indicator of intrinsic motivation) and of value and meaningfulness of the mathematical tasks and the activity (an indicator of identified regulation), which were generated through the implementation of this project.

Conclusions

In conclusion, our findings indicate that student motivation to engage in the math trails program supported by the use of a mobile app was complex. Both intrinsic and extrinsic types of motivation, as well as amotivation, were found in the reasons for completing the activity. However, we also found that students reported and demonstrated more intrinsically motivating rather than extrinsically motivating and amotivating factors for engaging in the activity. While intrinsic motivation was an essential part, identified regulation was also important. The design of the project and its technical implementation contributed to these results, as reported by the student through the self-report instrument, and it was demonstrated through their activities and work. Therefore, in the implementation of the MathCityMap-Project, we must be aware of the important role of influencing student motivation when designing a mobile app-supported math trail activity. The relevance and value of the task must be clearly identified and linked to the objective of the project. Most importantly, students must enjoy and be attracted to the activity, both in completing the math trail task and in using the mobile app. These are the main factors that need to be considered when implementing the MathCityMap-Project.

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SOUTH AFRICAN SCIENCE TEACHERS' VIEWS ON LANGUAGE USE IN SCIENCE TEACHING AND LEARNING: MESSAGES FROM LITERATURE AND LESSONS FROM CLASSROOM OBSERVATION

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Many teachers hold strong positions on the role of language in science. Some believe that allowing the use of home languages (HLs) in science classrooms disadvantages ESLs by denying them opportunity to develop proficiency in English as the LOLT and language of assessment. It would be expected that these teachers would make deliberate efforts to use teaching strategies that create opportunities for learners to engage frequently with language in science lessons. Both literature and empirical evidence from South African classrooms indicates that this is not the case in many science classrooms. I draw on data from a recent survey of South African science teachers' views on language in science as well as from classroom observations to illustrate teacher language practices in the classroom.

Introduction

The paper is based on an ongoing project on language in science. In this paper, I will present empirical data from a questionnaire of just over sixty secondary school teachers' views of language use in science classrooms and then use some illustrations from real classroom observations of teachers' communicative and language practices to illustrate what some teachers do to try and mobilise the linguistic resources of the science classroom.

The key argument in this paper is that many teachers hold strong positions on the role of language in science. Some believe that allowing the use of home languages (HLs) in science classrooms disadvantages ESLs by denying them opportunity to develop proficiency in English as the LOLT and language of assessment. It would be expected that these teachers would make deliberate efforts to use teaching strategies that create opportunities for learners to engage frequently with language in science lessons. Both literature and empirical evidence from South African classrooms indicates that this is not the case in many science classrooms. For diverse reasons teacher talk about learner language development is not always matched by relevant actions in the classroom. Many do not see the development of language as part of what science teachers do and others argue that it is the duty of language teachers to develop learner language proficiency. However, those science teachers who genuinely want to help learner language development find it difficult to do so as they are not adequately prepared professionally to do so.

Meanwhile, South Africa's department of basic education has adopted a policy for strengthening the teaching and learning of languages both as subjects and as LOLTs. In particular, the DBE is advocating the teaching of English across the curriculum (DBE 2014). Parallel to this is the increased focus on improving the teaching of African languages, focus on English First Additional language (EFAL) teaching and learning as well as literacy and numeracy in general, particularly at the lower levels of schooling. Research over the next few years should begin to show how these efforts are paying off for lower levels of schooling. However, the situation remains quite dire for the many secondary school learners who did not have the opportunity for early development of the requisite proficiency in English, the preferred LOLT in many schools. It is up to the teacher to come up with appropriate strategies to enable effective learning of science in spite of the language issues that prevail in such classrooms, including decisions on whether learners engage strictly in the LOLT or can be allowed to use their home languages for sense making during classroom discussion. Research in mathematics education indicates that mathematics teachers have moved from a place of struggle with this decision to working with learners' languages as a resource in the mathematics classroom discourse. No such research has been reported on South African science teachers' views of the role of learners' home languages in the science classroom. In this paper, I report on the views of sixty-four science teachers on language in the science classroom. I then show how one South African teacher mobilises the language resources of the science classroom to create learning opportunities for ESLs. The paper addresses two questions: What are science teachers' views on the role of language in the teaching and learning of science? How do some teachers mobilise the language resources of the classroom to enable ESLs learning of science?

Literature review and theoretical framework

The work of Rincke (2011) provides a useful tool for thinking about language in science classrooms. Rincke proposes three languages of science classrooms: the learner's home language; the language of instruction; and the language of science. Rincke further argues that research on second language learning is useful in understanding how ESLs might transition between the languages of the science classroom. According to Rincke, learning specific phrases is more beneficial for ESLs in acquisition of the target language than memorisation of single words. She argues that these specific or "automated phrases" have linguistic environment. For example, it is useful for ESLs when learning the words "decision" and "conclusion" to understand that one "takes or makes" a decision and "arrives" at a conclusion. Teachers therefore, need to "model scientific language by explaining to students how they themselves are combining terms together in sentences" (Rincke 2011, p. 235). Teachers are not always given the training and preparation required to be able to do what Rincke suggests for ESLs, much less so South African science teachers. In fact many science teachers would be trained to focus on the science subject and its teaching, rather than issues related to language. Yet for ESLs, the subject and the language that is conveying it cannot be separated.

Evidence from general reviews of research in mathematics and science education indicates that language is still under researched in science education (Alant & Malcom, 2004; Lerman, 2009; Venkat et al, 2009). A recent review of South African research on language in science education identified just over fifty papers in local and international journals. The research reported was categorised into four cross cutting themes: the use of language during classroom interaction; language and student performance in local and international tests; research on language policy; and research reporting stakeholder attitudes, views or perceptions of language. Research focusing on the first two themes has been published (Authors, 2017). A publication on research on language policy is currently under review for publication shortly (Authors in press). The remaining four papers reported research targeting teacher or student views on language. One was in fact a general study including but not specifically focused on science education research (De Wet, 2002). In a general overview of literature on language in education De Wet provided empirical data on experienced teachers and student teachers views on the importance of language in a number of disciplines, including science and mathematics. Mthiyane's (2016) was the only South African study of science learners' language preferences. The other two papers reported learner attitudes to home languages in assessment, specifically the role of language on performance in the TIMMS tests (Probyn, 2005; Zuma & Dempster, 2008). Clearly research on language in science has focused on English as a barrier to learning science and on strategies for coping with the linguistic demands of teaching and learning science in English. There is little research that reports stakeholder views on language in science and very little evidence of language practices in science classrooms in South Africa. In this presentation I will discuss some findings from the survey of teachers' views on language and then using Mortimer & Scott's (2003) model of teacher and student classroom interaction. I will illustrate how language plays out during the lesson as the teacher takes a variety of communicative approaches to engage ESLs in science learning.

Mortimer & Scott (2003) categorise classroom interaction along two axes, the interactive-noninteractive and the dialogic-authoritative. According to this model, classroom talk can be categorised into four types (See Figure 1). When the teacher takes an interactive/dialogic (ID) approach s/he engages learners in dialogue as s/he explores their ideas; in the noninteractive/dialogic (NID) approach only the teacher is talking, reviewing learners' ideas; in the interactive/authoritative (IA) approach the teacher involves the students in the talk but pursues a specific point of view (the scientific view); and in the noninteractive/authoritative (NIA) approach only the teacher is talking one point of view is expressed (lecturing). Thus, the teacher can shape and guide classroom interaction and particularly learner talk by selecting different communicative approaches for different purposes during the course of the lesson.

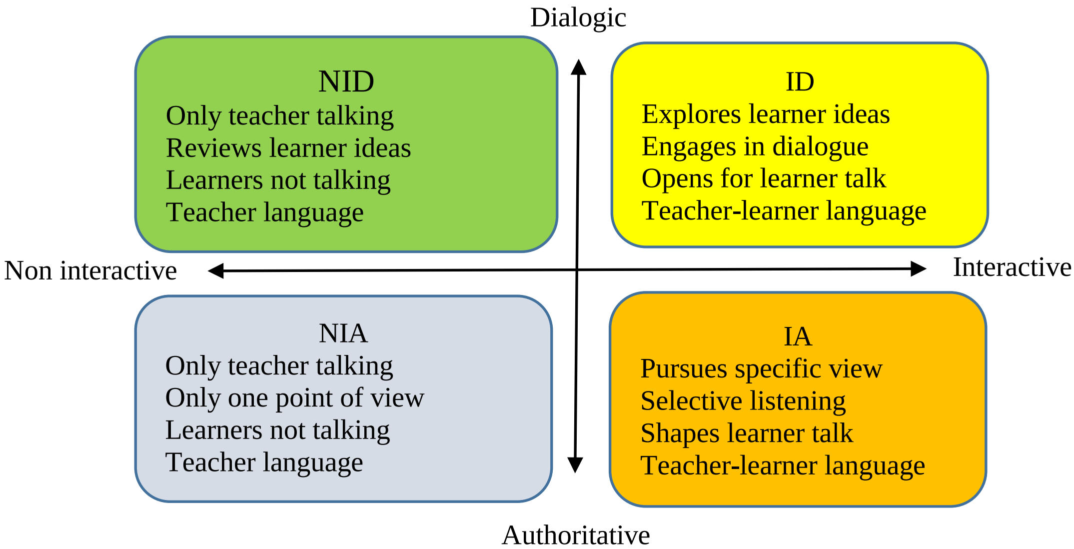

Figure 1: Mortimer & Scott's (2003) teacher communicative approaches

According to Vygotsky (1986) language is an important tool in this social mediation of learning. I used Mortimer & Scott's model to understand how language plays out in the social mediation of ESLs science learning. I wanted to understand how teacher and learner language practices vary, particularly during ID and NID communicative approaches. In the ID and NID, the teacher seeks to involve learners in the discourse of the classroom by eliciting their ideas and by shaping their talk towards a specific viewpoint or what Mortimer and Scott refer to as the scientific story. Language is an important tool in this interaction and where learners are not proficient in the language of instruction it is up to the teacher to determine whether and how the language resources of the classroom can be exploited and mobilised to mediate learning. I illustrate teacher-learner language practices in two classrooms. Due to space I only refer to one lesson from each classroom. I then discuss the implication of teacher language practices for ESLs learning of science.

Methodology

This paper draws on two data sets from an ongoing project on language in science in South Africa. The data that address the first question are from a survey of teachers' views on the role of language in science. Sixty four science teachers were invited to complete a semi structured questionnaire to indicate their views of language use in science classrooms. For this paper I only analysed responses regarding the teachers' language preferences for their own teaching and for their learners' engagement in class discussion.

The second data set is derived from observations of teacher and learner language practices in some secondary science classrooms. The teachers referred to were selected for the variance in their communicative approaches and the language practices that played out in their classrooms. I refer to a Grade 10 (learners 15-16 years old) biology lesson on biodiversity conservation. The lesson was audio recorded and the recording transcribed verbatim. I use excerpts from the transcripts to illustrate emerging teacher language practices during these lessons.

Findings & Discussion

To answer the first question, "What are science teachers' views on the role of language in the teaching and learning of science?" I analysed data from the survey of teacher language preferences to determine first, how many languages each teacher was proficient in. This would give an indication of the level of teacher multilingualism. For purposes of my study, the ability to speak a language was deemed sufficient proficiency for purposes of use of the language in classroom interaction.

No. of languages	**1**	**2**	**3**	**4**
No. who speak	4	36	21	3

Table 1: Teachers levels of multilingualism (n = 64)

According to Table 1 above, the majority of the science teachers surveyed can be regarded as multilingual. Most speak 2 or 3 languages, that is English plus one or two other local languages. From the qualitative information provided in the questionnaire all the languages that teacher reported proficiency in were shared with their learners. Thus, most of the teachers would be able to engage learners in their home languages and/or understand learner discussions conducted in their home languages. I then determined teacher language preferences for their own teaching and for learner engagement in classroom talk (Figure 2).

Teachers indicated a strong preference for the English language both for their own teaching and for learner classroom talk. Of the 64 respondents, 59 indicated that they can teach comfortably in English (Can teach in), leaving about five (of the 23) teachers who were not comfortable teaching in English. The remaining 18 could teach in both English and home language. Again the next two columns indicate that most prefer to teach in English (50) and many actually do teach in English (48).

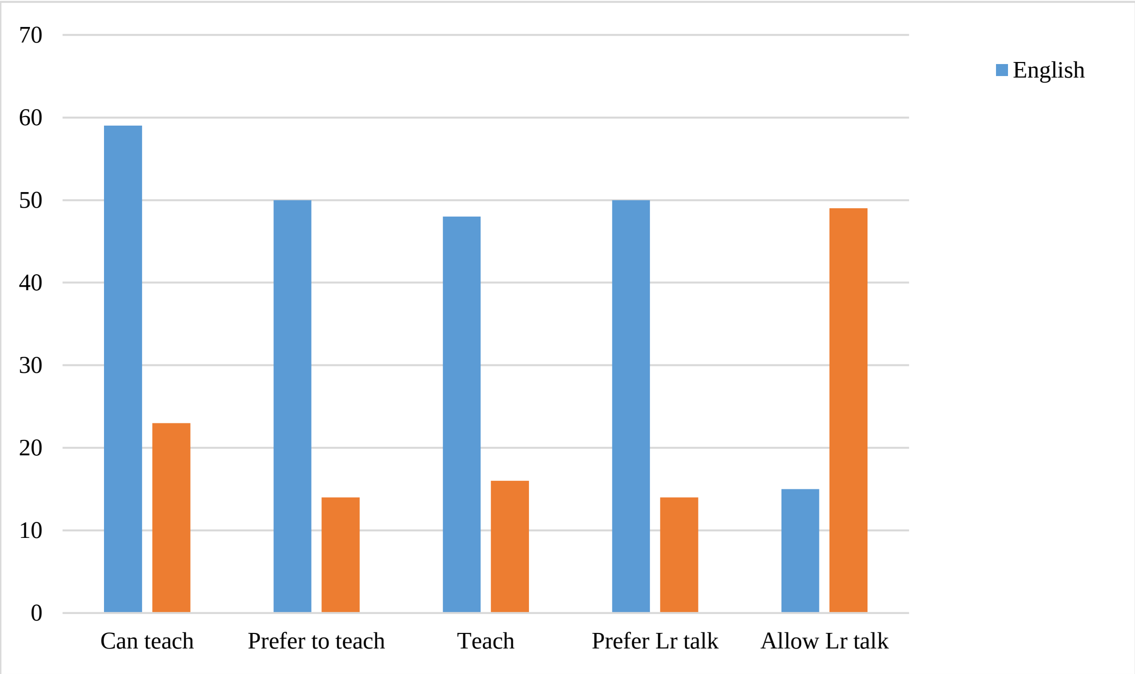

Figure 2: Teacher languages preferences for teaching and for learner classroom talk

Figure 2 illustrate a dichotomy in teacher language preferences for their learners. While most (57) prefer that learners engage in classroom discussions in English only 15 forbid the use of home languages in class, the other forty nine said they did allow their learners to use their home languages during classrooms discussion. Teachers' reasons for these preferences are consistent with those reported in literature for South African mathematics teachers. Most saw the use of the English language in teaching and for learner engagement in classroom discussion as an opportunity for learners to develop the requisite proficiency in English as the language of assessment (Setati et al, 2002; Rollnick, 2000).

To address the second question *"How do some teachers mobilise the language resources of the classroom to enable ESLs learning of science?"* I use examples from a biology lesson. In this lesson the teacher used a concept cartoon task which drew from learners own cultural knowledge of the owl to facilitate learner participation in classroom talk. The following excerpts taken at different stages of the lesson discussion illustrate the teacher's communicative approach and the language practices that emerged. The transcripts are in the language that the utterances were made in with English translations in bold.

163 Teacher: he says "Hhhm no way I would never introduce owls to my neighbourhood" *(and then to the class)* I overheard Lindokuhle say "No no". Now let's hear

why you wouldn’t introduce owls into your neighbourhood, Lindokuhle.

Lindokuhle: owl?

165 Teacher: yes what is it that you know? maybe it is something that you read in a book in a newspaper or you saw on the television?

Or if it’s something you learnt from your parents or in your community. So let’s hear about that.

Lindokuhle: ah Maam isikhova ah **(no Maam an owl no)**

SS: *(other learners chuckling and laughing soflty)*

Lindokuhle: isikhova? **(an owl?)**

Teacher: you said “No no no” now tell us why

170 Lindokuhle: isikhova? **(an owl?)**

Teacher: no just be free. Oh someone wants to help him

Nanelo: er Maam because many people believe owls are used to bewitch other people

The excerpt opens with Mrs Nkosi reading again from the cartoon character Dumi, who said that he would never introduce owls to his neighbourhood. She takes an interactive-dialogic (ID) communicative approach as she asks Lindokuhle why he said, “No no I would never do that”. Although Lindokuhle responds and attempts to come into the discussion, he struggles to go beyond repeated exclamations about an owl (turns 164, 166, 168 and 170). Normally, Lindokuhle’s response in turn 164 might be viewed as a request for clarification of the teacher’s question or confirmation of the subject of discussion. However, considering that he had just been in a group discussion on the topic and the teacher had just reread from the concept cartoon, his question “Owl?” suggests something different, a reluctance to talk about this topic. This is evident from his repeated question throughout this excerpt in spite of the teacher’s probing interventions and her attempt to provide cues and to create a safe space for open sharing. In turn 165, for instance, in typical ID approach, the teacher provides clues and suggestions of possible sources of information that learners could draw from for this discussion. In turn 171 she invites the learners to ‘feel free’.

The next excerpt illustrates another ID interaction episode. Nelisiwe caught the teacher’s attention when she leaned over to whisper something to her peer. The teacher then called on her to share her ideas:

193 Teacher: Nelisiwe, remember we are sharing information here.

Nelisiwe: about an owl?

195 Teacher: Uh-huh

Nelisiwe: Eh tjo Maam **(oh no Maam)**

SS: (laughing)

Nelisiwe: Tjo Maam li-violent **(Maam it's a violent word)**

Teacher: say it in vernacular

200 Nelisiwe: No Maam it (an owl) is a sign of death

Teacher: Hooh that's another issue. You see now?

Thabo: no Maam

SS: yes yes

Thabo: how?

205 SS: (talking noisily among themselves)

Teacher: no wait now does it mean that if an owl passes over my home…

SS: yes yes

Teacher: it means death

SS: yes yes

In typical ID approach the teacher exposed learner ideas without judging or evaluating. Like Lindokuhle, when she finally opened up Nelisiwe's engagement did not go beyond repeated exclamations about an owl. It was not possible to interview Nelisiwe after the lesson to probe her thinking further. However, from the nature of her responses and the tone of her voice in turns 194, 196 and 198 it would seem that a discussion about an owl was taboo for her. In her culture the owl symbolises death. This could explain her silence so far and her reluctance to participate in the discussion. Once again the teacher taking an interactive-dialogic approach attempted to open up the interaction using a variety of probes. The statement "Nelisiwe, remember we are sharing information here" (turn 193), for instance maybe reassuring to the learner that the classroom is a safe space to share her thinking. Indeed a few turns later Nelisiwe begins to articulate the problem that "it's a violent word" (turn 198). The teacher sensing that there is more to Nelisiwe's response, identifies language as a possible barrier to the communication and urges the learner to "say it in vernacular" (turn 199). Although the teacher herself never used the vernacular in the lesson she was open to learners' use of their home languages.

Later in the lesson the teacher took a somewhat interactive-authoritative approach to begin to guide the talk from the cultural knowledge of owls to the biology goal of the lesson. Nkululeko had volunteered an argument based on the biology of the owl:

246 Nkululeko: er Maam kahle kahle into nje okumele abantu bayazi ukuthi

iskhova nje asidalelwanga ukuhamba emini sihamba ebusuku
yikho nje abantu bethi iskhova siyathakatha **(er Maam what people should know is that an owl was not made to be active during daytime it comes out at night that's why people say an owl is a witch)**

Class: yes yes

Teacher: oh ok

Nkululeko: asikwazi kahle ukuhamba emini **(it does not move around during the day)**

250 Teacher: it is nocturnal not diurnal so people may be justified to believe that it is used for a negative purpose because it is not seen during the day.

The teacher took up Nkululeko's contribution and using an interactive-authoritative approach she shifted the focus of the discussion from beliefs about the owl, which had been the focus so far, to the biology of the owl. In turn 250, she followed up on Nkululeko's assertion (in turn 246) that the owl does not move during the day by inserting the scientific terms nocturnal and diurnal. She then elaborated on Nkululeko's argument that in light of the evidence available then people were justified to believe the way they did about owls (turn 250)

This interaction continues in the next excerpt from a later episode:

333 Nkululeko: okunye Maam ukuthi iskhova sibalulekile for human beings.
Iskhova okokuqala sidlamagundwane lezezismoshela thina impahla
(owls are very important for human beings first, an owl eats rats that destroy our property)

Teacher: so that's a positive

335 Nkululeko: esinye sidli inyoka lezi ezisibulalayo (some eat snakes which kill us

Teacher: two that's a positive again

Nkululeko: so yikhoke ngithi sibalulekile iskhova **(that is why I say an owl is important)**

Teacher: so it is very important in the food chain. There will be less snakes there will be less mice in our environment

Nkululeko's argument in this excerpt further shifted the discussion to the importance of owls based on their biology (turns 333, 335 and 337). He however, did not use the appropriate scientific terms and this would keep the discussion within the realms of everyday knowledge. The teacher took up his idea in turn 338, and used it to point out both the positive role that owls play in the environment and the scientific explanation for this role, "so it is important in the food chain ..."

While this form of engagement often came through as a strength in her pedagogical style, the teacher could have deepened learner engagement with the science content of this lesson by taking first an interactive-authoritative (IA) approach and then both a non-interactive-dialogic (NID) and non-interactive authoritative (NIA) approach to pursue the line of argument in the last excerpt above and to infuse the conservation biology content. For instance, in the IA she might probe learner understanding of the biology of the owl itself and that of the energy transfer in the food chain/food web. At this point she should avoid providing the scientific terms herself and challenge her learners to do so. Through NID and NIA interaction she would then use the learners' ideas to develop the conservation story and provide further explanations. In this case she would be responsible for making explicit both the language of biology and the English language in which the interaction is happening.

Conclusions

South African science teachers' views of the role of language in the classroom are varied and influenced by a perceived need for learners to develop proficiency in English as the language of assessment. However, teachers still see the need to allow learners to engage in their home languages for purposes of constructing understandings of science content during classroom discussion. Using excerpts from a biology lesson this paper illustrated how one teacher adopts different communicative approaches to facilitated learner participation in the lessons while opening up to the use of all language resources in the classroom. For the most part teachers struggle to get the learners involved in classroom talk even with what seem to be appropriate tasks for the purpose as was the case with the owl lesson. There is therefore a need for research evidence on best possible teacher practices in ESL science classrooms to inform teacher education on how to empower teachers to be able to mobilise the language resources of the classroom for effective learning of science. Specific data on science education stakeholder views of language and actual teacher practice in the classroom is critical to inform adequately the policy and practice debates on language in science education.

Acknowledgements

I acknowledge the teachers and students who allowed the collection and use of this data.

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DIFFICULTY, DISCRIMINATION, AND SUCCESSIVE DISCRIMINATION CURVE: INSIGHTS FROM NATIONAL PHYSICS OLYMPIAD EXAM 2016

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One of the key aspects of the selection process for any examination is the quality of the question paper. Exams like Indian National Physics Olympiad (INPhO) tests examines understanding at a higher level and aim at selecting top 10% examinees for next level of the selection process. This higher secondary level exam has 5-6 subjective guided questions to be solved in a time span of three hours. Multiple choice questions are easy to analyze and grade but a subjective question is difficult to grade and examinees are also eligible for partial marks. Many times there are more than one ways to solve a problem. In such a scenario what should be the ideal criteria to decide the effectiveness of a subjective question paper? The efficiency of an item can be judged with several parameters. Commonly used indicators such as average marks and standard deviation give a superficial idea about the performance of a question. This study aims to look at INPhO 2016 questions performance in light of some other parameters used in education measurement theory such as difficulty index and discrimination index. An extended form of discrimination index, namely successive discrimination curve (SDC), is also proposed to compare discrimination levels at different ability levels.

Introduction

Olympiad test pattern

The test paper had six close-ended, guided questions consisting of several subparts and covered almost all aspects of higher secondary school level physics syllabi. Questions also test the reasonable amount of mathematical skills required to solve tasks at International Physics Olympiad. The examinees were required to attempt and solve the entire test paper in three hours. Content validation of the questions was done by a national committee of subject experts. Question paper can also be accessed from Olympiad website (HBCSE Olympiad website). The members of the question paper setting committee have been part of Indian delegations in past International Physics Olympiads (IPhOs). Examinees have to show the workings of their answers. The grading scheme incorporates all possible solutions with least count up to 0.50. To maintain uniformity, each grader grades only one question for all the answer scripts. In 2016 test, 326 examinees appeared, out of which 41 were selected for the next level.

Assessment tools

There are basic parameters such as average and standard deviation which give modest information about a question. A high average value with a small standard deviation may indicate that question was easy for a large population. The reverse is true for a difficult question. We will use following parameters to analyze subjective questions: (i) histogram (ii) difficulty index (iii) discrimination index (iv) successive discrimination curve (SDC)

Histogram

Histogram of total score can be used to see if overall test paper was easy or difficult. It can be negatively skewed, positively skewed, normal or even bimodal. A negatively (positively) skewed histogram means an easy (difficult) test. Having two peaks (one at the low score and another near high score) indicates a bimodal distribution and might be useful to discriminate scores well. For a test like INPhO which aims to discriminate top 10% examinees, one can expect any of the above graphs except for a negatively skewed. Similarly, a histogram of individual questions can also give meaningful insights. A well-constructed test's histogram should result in a normal distribution.

Difficulty index (F)

Difficulty index or facility is the average marks for each question. For example, in a test, a question carries 10 marks. Let $n_1, n_2, n_3 \dots n_N$ respectively depict each examinee's score in that question. Here N depicts the total number of examinees taking the exam. Difficulty index for a question is calculated as:

$$\text{Difficulty index } (F) = \frac{n_1 + n_2 + \cdots + n_N}{N \times 10}$$

Higher the difficulty index easier the question is (Ebel, 1986) suggested including moderate difficulty level questions to achieve a better discrimination. However item difficulty level sometimes may not indicate an appropriate discrimination power. For example, half the examinees get the correct answer and if most of the examinees are in lower ability group, the question is not successful in differentiating examinees of different levels. An ideal interpretation of the difficulty index values is given below (Wright, 2008):

$0.75 < F < 1.00$	Easy item
$0.25 < F < 0.75$	Average
$F < 0.25$	Hard

Discrimination index (D)

It is assumed that examinee's total score in the test represents her ability. As the name suggests, discrimination index is used to determine how well a question has performed to discriminate examinees of various ability levels. For subjective questions or questions with quasi-continuous score pattern, one can use Pearson product moment correlation (r) between item's score and corrected total score of the test (Kline, 2005). Corrected total score is obtained after removing that item's contribution from the total test score. This is important if test has few questions and contribution of individual item's maximum contribution may change r siginificantly. Correlation value 0.70 is considered as a good correlation value (Deale, 1975).

For multiple-choice items, one can take the difference in fractions of examinees getting an item correctly in the top subgroup and a bottom subgroup of the population is calculated. Kelly (1939) suggested that a more sensitive subgroup to calculate discrimination index is 27%. Ebel (1986) provided following guidelines to select a multiple choice item:

- $D \geq 0.40$, very well-functioning items.
- $0.30 \leq D < 0.40$, reasonably well-functioning items.
- $0.20 \leq D < 0.30$, marginal items which need revised.
- $D < 0.20$, poorly-functioning items which need eliminated or fully revised.

INPhO does not have any multiple choice questions. Above range is discussed for the sake of completeness. Though we cannot analyze D statistically, it is widely used by teachers (especially for multiple choice questions) for the ease of interpretation. Akin to this definition, for subjective type questions one can calculate D as (Wright, 2008):

$$D = \frac{\text{median of top 27\% group} - \text{median of bottom 27\% group}}{\text{maximum range of score}} \qquad (1)$$

Here the maximum range of score = (maximum score – minimum score) among all examinees. We pause here to justify the use of median instead of mean. Median is not affected by the outliers or the extreme scorers at the end. Since it is the middle score when students are arranged in rank wise, it is a better measure of student's average performance when data has extreme scores. An example of using mean for calculating discrimination index can be found in Hoshangabad Vigyan article (Hoshangabad, 1983).

Also, note that an absolute value of D is not important. It is a range which decides the effectiveness. An item that appears highly discriminating in one small sample may appear low discriminating in another small sample. Smaller the sample of analysis, larger the sampling error is. Still it can provide a mean of test improvement.

Successive discrimination curves (SDC)

Discrimination index compares only top and bottom examinees. It completely misses the mid-ability level examinee's performance. Test (INPhO) discussed in the present article is used for selecting top 40 examinees (nearly 10% of total) for the next level of exam. It is important to know how a question discriminates across all the ability ranges. We propose following exercise:

Divide the total population into subgroups of 40 examinees to calculate D between successive groups and plot the D values on a same scale. Number of examinees in each subgroups can be decided as per the purpose of the exam. We chose each subgroup to consist of 40 examinee since our test aims to select as many as examinees.

The discrimination index for various subgroups are indicated by:

$D_{12} = D$ for rank 1-40 vs 47-86

$D_{13} = D$ for rank 1-40 vs 127-146

… … …

$D_{18} = D$ for 1-40 and 287-326 etc.

In order to have the same number of examinees in each group, six examinees are discarded from 41st – 46th rank, to make it a total of 320 examinees. One can also plot the value of the median score of each group but SDC will immediately give a comparative performance across the subgroups. The idea of defining such curve is to take advantage of continuous score range of subjective questions. Ideally, SDC should continuously increase when plotted from D_{12} to D_{18} and not dip.

INPhO 2016 assessment

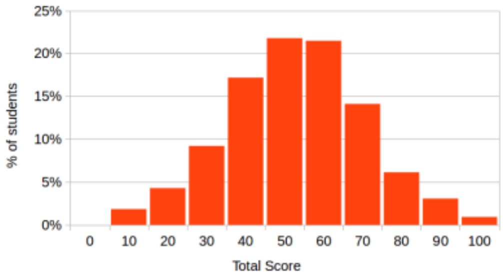


Figure 2: Histogram of the total score of the test. Question scores and percentage of students in the range are displayed on horizontal and vertical axis respectively

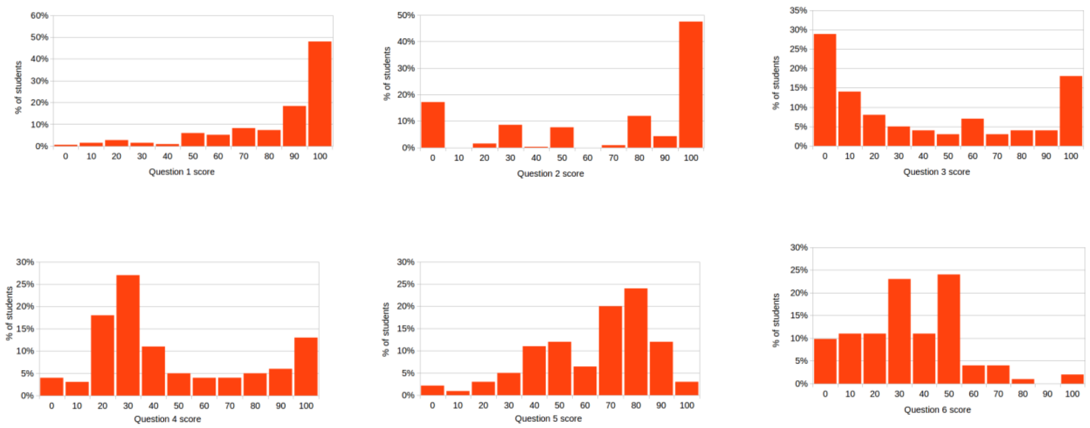


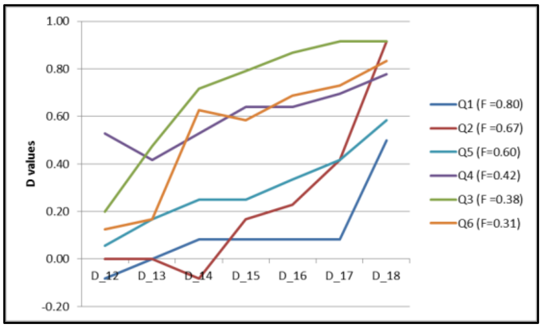
Figure 3: Histograms of question's scores. Clockwise from top: question 1 to question 6. Question scores and percentage of students in the range are displayed on horizontal and vertical axis respectively.

A histogram of examinees' performance in INPhO is shown in Figure 1. This is almost a symmetrical distribution with average marks 48.2% and standard deviation 18%. Seventy percent of examinees scored between plus or minus one standard deviation of the mean. Majority of them (94%) scored between two standard deviations. We can say that histogram is a bell curve which is expected from a well-constructed test (Wright, 2008). Examinees have already passed one level of the exam to appear in the test. Hence you do not expect a highly skewed curve. It also uses all the available range in the test which is a good sign. Also, note that a total of 42 examinees were selected with a cutoff at 69%.

Questions in the tests are ordered according to increasing difficulty level. In INPhO 2016, Q1 is easiest and Q6 supposed to be most difficult. However, examinees are free to attempt the paper in any order and this may considerably affect the overall score in the test. Hence we cannot draw any firm conclusion from difficulty index of the total score. Table 1 shows all the relevant indices for the questions. For a better interpretation, in Figure 2 questions are arranged in increasing order of difficulty level along with other parameters.

	Q. 1	**Q. 2**	**Q. 3**	**Q. 4**	**Q. 5**	**Q. 6**	**INPhO Total**
Marks allotted (% of total)	12	8	20	18	18	24	100
Difficulty index	80	67	38	42	60	31	48
***D* using Eq. 1**	0.25	0.75	1.00	0.50	0.28	0.35	
Pearson (r) for corrected score	0.39	0.48	0.42	0.36	0.33	0.40	

Table 1: Parameters for questions.



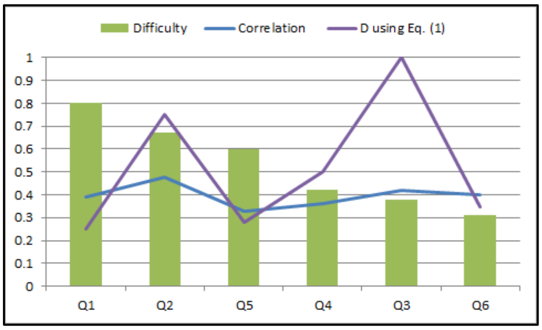


Figure 5: Successive discrimination curves for the questions. Difficulty index is also indicated in the legends.

There is a notable difference in the ranges of D and correlation. They derive contradictory conclusions, especially for Questions 3 and 2. This is due to mid ability level students' score inclusion in the correlation calculation. Except for Q2 and Q5, correlation values are not far from each other. Hence we prefer to analyze the question by critically looking at D and SDC which is plotted in Figure 4. Analysis is summarized in Table 4.

Q	**Histogram**	**Difficulty**	**Discrimination**	**SDC**	**Conclusion**
1	Negatively skewed	Easy	Poor	Flat for most ranges.	Needs modification
2	Bimodal, dichotomous	Easy	Best	Low discrimination up to mid ability level	Good question
3	Bimodal, dichotomous	Difficult	Best	Ideal curve, linearly increasing. Low among high ability group	Best question
4	Bimodal	Difficult	Good	Ideal curve, high discrimination power among high ability group	Best question
5	Negatively skewed	Moderate	Poor	Low discrimination up to mid ability level	Average question
6	Positively skewed	Very difficult	Poor	Low discrimination among high ability group	Needs modification

Table 2: Relative analysis of the questions. Here discrimination power is assessed based on D value and not by correlation.

Question 6 is a difficult question of the test but with a low discrimination value. This question should be reexamined. This was the last question of the paper and there may be other reason for a high difficulty value such as fatigue or time constraints. Hence Qs 3 and 4 turn out to be the ideal questions for this test.

Conclusion

Education measurement statistics is a widely used concept among teachers. Measures like average and standard deviation do not reveal all facts about the performance of the question. Several parameters have been defined for multiple choice questions but there exists a lacuna for subjective question performance testing. We use histograms, difficulty index, discrimination index and newly proposed successive discrimination index to see the usefulness of the questions. It is demonstrated that the effectiveness of the question cannot be solely measured by the popularly used difficulty index alone. Difficulty coupled with the discrimination index provide a meaningful insight on questions. The SDC validates the outcome and reveals discrimination power of the question throughout all the ability ranges. One can choose smaller subgroups to look at question's performance critically. A dip in SDC is a signal to investigate further and specific students can be interviewed based on the outcome. Hopefully, this will aid in improving questions for future use.

Acknowledgements

I sincerely thank discussion with question committee members. This work is supported by Government of India's Indian National Olympiad program. I also thank anonymous referees who helped in tightening the manuscript.

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Question paper is available at:

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MATHEMATICS TRAINING AND TALENT SEARCH PROGRAMME: A REPORT

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Mathematics education at university level in the current Indian context lacks rigorous research and pedagogical innovations. The Mathematics Training and Talent Search Programme (MTTS) is one of the few alternative initiatives in higher education that enables students to appreciate and understand mathematics in a constructive manner. This paper tries to look at the journey of MTTS through its history, design, curriculum, pedagogy and assessment, and locate it in the context of current mathematics education scenario in India. The observations and reflections in this report are based on the author's engagement in making a documentary film on the MTTS programme. Creative initiatives such as MTTS are not only necessary for improving quality of higher mathematics education but also required for ensuring meaningful engagement of students with the discipline of mathematics.

Introduction

In a large developing country like India, catering to diverse needs of education has not been easy. When it comes to mathematics education at university level, the complexity increases manifold. Some of the challenges include: (1) improving basic training in mathematics, (2) enhancing the quality of teachers, and (3) improving the learning process by meaningful and engaging teaching practices. In 2015-16, the number of students enrolled in mathematics was 1,29,604 which is the highest among all the science streams. Of these, 60.4% are female students, which is also the highest among all science disciplines (MHRD 2016b). Given such a large number of students, it becomes all the more necessary to create meaningful learning experiences about mathematics. This task is complicated by the fact that there is little research on teaching-learning in higher education in India. (MHRD, 2016a, page 124)

Mathematics Training and Talent Search Programme (MTTS) is a national level four-week intensive summer training programme in mathematics. It has been running for the last 25 years in India, and is funded by the National Board for Higher Mathematics (NBHM).

This paper focuses on the innovative methodology of MTTS and implications it can have on university level mathematics education in terms of research and practice. The observations and reflections in this report are based on the author's engagement in a documentary[1] film making of the MTTS programme. The preparation of this report was based on semi-structured interviews with eleven facilitators, six

[1] The documentary was made in collaboration with mathematics magazine *Bhāvanā*, in the occasion of silver jubilee celebrations of MTTS programme.

core-committee members (out of seven), and twenty former participants of the MTTS programme. It also involved attending and observing the classes, and interviews with 30 students.

History and evolution of MTTS

Venkataraman et al (2012) argue that teaching mathematics, in most institutions, is reduced to stating and proving a theorem or solving exercises behind every chapter and learning is reduced to blind imitation of the content taught. The authors further discuss that every student is given structured lectures and is made to copy notes from blackboard, which has reduced them into passive recipients in the learning process. They exemplify how a student capable of scoring very high marks is unable to answer relatively simple questions on definitions, examples or counterexamples.

In 1989, there was a similar discussion about quality of mathematics education at higher level during a conference on Mathematics Education organised by NBHM at IIT Bombay in 1989. Professor S. Kumaresan proposed the idea of starting a summer training programme with an alternative teaching methodology to address these issues. This new methodology emphasised the need of abandoning well-structured and polished lectures. It suggested that the students should be actively involved in the classroom and participate in learning through discovery. The new methodology was based on the experiences and experiments of Prof. S. Kumaresan from teaching regular classroom courses. This training should expose students to the excitement of doing mathematics. The NBHM agreed to fund such a programme with national scope. The first programme was held in the summer of 1993.

The aims of MTTS, quoting Kumar (2017) are as follows:

1. To promote active learning, to expose motivated young minds to excitement of doing mathematics and to inspire them to take a career in mathematics.
2. To promote independent thinking and problem solving ability in mathematics.
3. To provide a platform for the talented students to interact with their peers and experts in the field.
4. To improve the teaching methodology of mathematics, in the country, in the long run.

The programme was conceived to be holistic in nature and inclusive in scope. MTTS envisioned students to become research workers in leading departments across the world, or teachers at higher secondary level to university level depending upon their aptitude and interests.

In the initial phase, the instructions and the tutorials were not integrated. This did not lead to expected interactions and achievement of learning through discovery method. Through self-evaluation process, the curriculum and pedagogy were restructured from 1995. The faculty had come to terms with the idea of interactive classrooms and development of the subject knowledge through examples and experiments.

Based on experience and feedback from the participants of the programme, many new features were introduced on experimental basis, such as encouraging them to work in small groups, student seminars, students reading an unseen passage and trying to identify the core ideas (which are usually not apparent), i.e. reading in mathematics, along with daily assignments.

Over the span of 25 years, MTTS has evolved into three distinct streams, namely, MTTS, mini-MTTS and Pedagogical Training for Mathematics Teachers programme (PTMT). Due to limitation of resources and seats, a large number of interested students do not get a chance to participate in MTTS programme. In order to provide opportunities to large number of students at regional levels, mini-MTTS programmes are organized in various places for one or two weeks at level-O. In order to familiarize mathematics teachers teaching at undergraduate and postgraduate levels with the methods followed in MTTS, two-week PTMTs are organised. These streams of programmes have been organized in 40 different institutions across 20 states in India till date.

Design, structure and curriculum

At present, MTTS has three levels: level-O, level-I and level-II. Level-O is meant for second year undergraduate students of mathematics, level-I for third year undergraduate students of mathematics, and level-II for the graduate students of mathematics. Sometimes, very bright first year undergraduate students of mathematics are also admitted to level-O. Usually, there is one main camp consisting of all three levels every year. Apart from this main camp, 3 independent camps for level-O are also conducted through the year.

Every MTTS camp consists of five stakeholders: a local coordinator, facilitators, students, teacher participants, and tutors. Local coordinator is a faculty member in the hosting institute who takes care of the managerial and logistical aspects of the camp, and ensures the young participants stay healthy for four weeks and the academic activities proceed smoothly. The coordinator, through informal communication with the students, often acts as the bridge between the academic and young participants.

The facilitators for this programme come from various leading institutions of the country (not confined to the host institute), and are experts in the field, known for their teaching and commitment to mathematics education. There are four facilitators per level. As a rule, each course is taught by a single expert. A facilitator is required to be present for all the sessions of a day. All the four facilitators of a level actively help the students identify the difficulties at individual level.

A teacher who is interested in learning about the methodology of MTTS is encouraged to participate in PTMT and/or MTTS as a teacher-participant. As a teacher-participant, she acts as a tutor inside and outside the classroom, where her role is to actively engage with students during problem solving sessions, group discussions, etc. A past student participant of MTTS, who is very familiar with the methodology, or a new faculty who wants to teach in MTTS are assigned the role of tutors.

The programme is widely advertised with the call for applications made on the official website, in newspapers, direct posters to colleges and universities and through emails to past participants. The application process is now fully online. Typically more than 2000 applications are received, with the selection criteria being a consistent academic record and the recommendation letter of a teacher closely acquainted with the student. Proactive efforts are made to encourage students from regional and rural backgrounds. In fact, to ensure this objective, the level-O of this programme is also arranged in various parts of the country.

The daily programme typically consists of five sessions: three morning sessions and two afternoon sessions. A weekly timetable is given below (for all levels):

	Slot I	Slot II	Slot III	Slot IV	Slot V
Week 1	Session (Lecture/ Problem Solving/ Tutorial)	Session (Lecture/ Problem Solving/ Tutorial)	Guided group discussion	Session (Lecture/ Problem Solving/ Tutorial)	Session (Lecture/ Problem Solving/ Tutorial)
Week 2	Session (Lecture/ Problem Solving/ Tutorial)	Session (Lecture/ Problem Solving/ Tutorial)	Group discussion	Session (Lecture/ Problem Solving/ Tutorial)	Session (Lecture/ Problem Solving/ Tutorial)
Week 3	Student seminar	Session (Lecture/ Problem Solving/ Tutorial)	Group discussion	Session (Lecture/ Problem Solving/ Tutorial)	Session (Lecture/ Problem Solving/ Tutorial)
Week 4	Student seminar	Session (Lecture/ Problem Solving/ Tutorial)	Group discussion	Session (Lecture/ Problem Solving/ Tutorial)	Session (Lecture/ Problem Solving/ Tutorial)

The subjects covered in the camps are as follows:

Level-O: Foundations of Mathematics (first two weeks only), Linear Algebra, Real Analysis, Number theory (first two weeks), Group theory (last two weeks).

Level-I: Linear Algebra (first two weeks only), Real analysis, Topology of metric spaces, and Group theory.

Level-II: Linear Algebra (first two weeks only), Complex analysis, Topology, and Algebra.

Excerpt from daily time-table: all subjects are included on each day.

	Session I	Session II	Session III	Session IV	Session V
Monday	Subject 1	Subject 2	GD	Subject 3	Subject 4
Tuesday	Subject 4	Subject 1	GD	Subject 2	Subject 3

Pedagogy & Assessment

Individual attention to students

In the beginning, each student participant in level-I and level-II is given a questionnaire to fill. This questionnaire consists of questions asking the student's familiarity with concepts that are assumed to be prerequisites for the level. The student answers how confident she is about every concept. After the orientation session, the level-O students start their course on foundations of mathematics which covers Logic, and Set theory. Students of level-I and level-II undergo a counselling session where each one of them is interviewed personally by a faculty of that level and asked some basic questions about the concepts. When the faculty thinks the students has not acquired enough knowledge in one or more particular field she is asked to attend that particular class a level below (time-table is designed in such a way that this transition is smooth). Some students who have not acquired enough knowledge in more than one subject is asked to attend a level below. The syllabus for each subject to be taught in a particular level is decided by the faculty in consultation with core committee depending on performance of the students. The aim is to make sure that every student is engaged meaningfully in learning important mathematics than how much they learn. Every student is provided a kit of materials such as textbooks, writing materials, expository articles, a souvenir, and sometimes a CD of useful open and free software.

Interactive teaching

The courses in MTTS are radically different from what is done in formal academic courses. The facilitator is discouraged from delivering polished lectures. The principle followed is "To teach and to learn is to think." All sessions are interactive and the students are made to actively participate in learning process in the classroom. When a new concept is introduced or a new result is proved, students are given typical situations and problems. The facilitator guides students to think and come up with ideas. As soon as the definitions are made, many examples are given and the students have to verify that they are examples or non-examples of the introduced concepts. The facilitator proceeds further if she is convinced that the majority have understood. Sometimes another facilitator, who is present in the class, may try to explain in her own way to give a different flavour of the concept. This gives a holistic perspective to the concept. The facilitators make references to analogous, concepts, or similar results introduced by her colleague.

Emphasis on daily assignments and writing exercises

Usually students are given outlines, strategies or the idea of the proof and they are asked to work out the details in the class itself. In the initial stages, the students are told how a typical proof along the lines of a textbook is written. Such exercise is to be submitted, in detail, as writing assignments. The students are encouraged to discuss the final proof. According to the facilitators this activity has two benefits: (i) those who did not understand or could not work out the complete details will have the chance to learn it thoroughly by discussing with theirs peers and (ii) those who did understand will get a chance to enhance their communication skills and consolidate the understanding, while they explain or clarify the questions of their friends. These assignments are checked by the facilitators. The common mistake or misconceptions are explained in the classroom. Otherwise the assignments are discussed with the students individually and suggestions for improvement are given.

It is commonly observed some of the 'brighter' students answer aloud when a facilitator asks a question. This can lead to a stage where other students do not try to understand the question as they know that 'some good students' will give out the answer. To prevent this, all students are made to write the answer very briefly, which will be examined by the tutors and the facilitators present in the class. This allows one to identify the problem area of the students and to take remedial measures.

Student seminars

Student seminars are integral parts of the programme. After two weeks, one of the sessions is completely devoted to students' seminars. The topics of the seminars are either chosen by the student or assigned by teachers taking the student's previous knowledge and understanding into account. The facilitators think that this serves two purposes: (i) it builds the confidence level of the students, and (ii) it removes stage-fright and the fear of talking in front of experts. The students follow the methodology of MTTS, while giving seminars, making their presentation highly interactive. In fact, in some of the students' seminars, hardly anything is written on the board. This aspect is so central that almost every student is given a chance to give a seminar, and in some cases some students give two seminars.

Group discussions

Since the last decade, group discussion are integral part of the programme. Students are divided into groups of four to five and are encouraged to discuss topics that have been introduced to them. Although the facilitators are present during these sessions, they do not interfere. Only when some group has a doubt, which no one in the group is able to resolve, a tutor or facilitator helps them. At times each group is assigned some topic or assignment for discussion, which they need to present at the end of the class. Every group is shuffled after every few days. This feature has been successful and appreciated by all the participants. The students spend more time in group discussion after the sessions.

In the first week, group discussions are guided with very specific objectives. The facilitator forms groups and assigns specific tasks for each group and the tutors guide the groups in this period in performing the tasks with questioning, finding strategies, addressing difficulties and resolving the problems. These initial guided group discussions help students to develop rapport with each other and also help facilitators understand all the participants personally.

Nurturing students to think independently

From the beginning the students are discouraged to take notes in the classroom. It is believed that this not only forces students to pay attention to the class but also to interact with peers after the class. During the initial few days, simple thinking exercises[2] are given to the students. They are supposed to go through them and discuss with their peers. Gradually, the difficulty level of these assignments is increased. After a few days, writing assignments are given every day. It is made explicit to students that there are no formal exam during and towards the end of the programme. This is to encourage students to learn mathematics for its own sake and to get out of the mindset of exam-oriented learning. However, every student is informed that their performance is critically evaluated through their regular assignments, student seminars, and their participation in classroom as well as in group discussions. The facilitators of a particular level collectively award a grade to each participant, which will not be

[2] The first thinking exercise is to find the pattern of the daily timetable by looking only at first two rows.

disclosed to the student. Continuous informal evaluations of each student are made and the participants are provided comments based on them.

Discussion among the facilitators

Some facilitators feel that MTTS is like a pedagogical lab where one can come with some ideas on how the flow of a course should be and try that out, which cannot be done in regular classrooms. Since collaborative teaching is involved, many myths[3] about teachers are resolved. This also gives scope for subject experts within mathematics to learn and appreciate how a concept can be seen from the perspectives of other fields. Collaborative teaching also helps in getting instant feedback from colleagues which can improve the performance of a facilitator in terms of teaching.

At the end of the first week, students are asked to fill a feedback form with their comments about overall experience of the programme. This is followed up by a meeting among all facilitators, tutors, and local coordinator to discuss about the issues raised and strategies to address them. At the end of every week, the facilitators meet and discuss about the academic performance of their colleagues and students in the previous week. At the end of the last week, every student is asked to write a detailed feedback about how they would evaluate their performance, and performance of all facilitators and if any issues need to be addressed. This is considered as anonymous evaluation of that particular camp by the participants. Every facilitator and tutor goes through every feedback form and takes note of critical points. This is followed by feedback meeting about the camp by the facilitators. Some suggestions to improve the quality of next camp are noted down. This is followed up by addressing the students on the last day about their queries, suggestions, and feedbacks.

Challenges and implications for policy

A programme of this nature has a lot of implicit and explicit challenges to face. First among them is scaling up the programme to cater to larger group of audience. The crucial challenge in this aspect is finding both financial support and human resources. A dedicated faculty, who has to spend resources and time to act as a local coordinator is difficult to find with available funding. Even in case one is interested, the hosting institute should be able to provide infrastructure and facilities for four weeks.

Facilitators who are interested in teaching-learning process and quality of higher mathematics education, and who can let go of their summer vacation and dedicatedly spend four weeks, are also very difficult to find. Even if they are interested, it usually takes about three to four camps to get them well-versed in the methodology of MTTS. To address the issue of reaching larger audience, the other streams (mini-MTTS and PTMT) were started. But they themselves pose some difficulties: mini-MTTS is typically held for one week which is not sufficient for a student to learn and appreciate the methodology. Though the teaching performance of participants of PTMT improves, they do not tend to use this methodology in regular classrooms citing various practical reasons such as lack of motivation among students and time constraints.

[3] According to Alsina (2001), some generally existing ‘myths’ and practices in mathematics education negatively influence the quality of mathematics teaching such as the self-made-teacher tradition, context-free universal content, deductive organization, top-down approach etc.

This methodology is not based on any standard theory of learning and based mostly on experiences of the facilitators. New facilitators are inducted into the programme by having them directly observe, engage and learn. Even after gaining experience as a facilitator, when it comes to regular classroom teaching, they tend to fall back on well-structured lecture methods which do not create much of an impact in university education. This programme completely avoids using Information and Communication Technology (ICT) in teaching learning process. It is perceived as a distraction from learning than a supplement to learning. MTTS has to think about integrating ICT with their pedagogy.

However, MTTS has impacted positively on a lot of female student participants in term of taking mathematics as a career option. They mentioned that if it were not for attending MTTS, they might not have realised their potential and pursue higher education in mathematics (Kumar, 2017, and interviews with alumni and committee members). This programme has created such an impact that similar programmes are started on experimental basis for subjects like physics and statistics. The success of the programme also led to starting Advanced Foundational Schools for first year PhD students which is run by National Centre for Mathematics.

The past student participants of programs have given positive testimonials about the programme (see Kumar, 2017). They say that at the end of the programme, their critical thinking ability, mathematics writing, and problem solving abilities have improved. Approximately, 4500 students have attended MTTS main camps of which 3000 have attended all the three levels. Of these, around 500 have earned PhD or are pursuing their research degrees. Many of the past participants have become mathematics teachers in schools up to university levels. This aspect makes MTTS one of the most significant and successful training programmes in the country.

National Policy on Education recommends that there should be more research on teaching learning process in higher education in India (MHRD 2016a). The methodology of MTTS could be a starting point towards this direction.

Acknowledgements

The author would like to thank Professor S. Kumaresan, director of MTTS, for giving permission and complete cooperation to film the programme and Bhāvanā team, Professor C. S. Aravinda and Mr. Sudhir Rao, for funding, planning and co-creating the film. The author would also like to thank core-committee members, faculty, former participants and students for their participation and support.

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A CRITICAL EVALUATION OF A TEACHER PROFESSIONAL DEVELOPMENT MODEL – A CASE STUDY OF A PHYSICS PRE-SERVICE TEACHER

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Teaching and learning physics is a challenging endeavour, especially for trainee teachers embarking on the Post Graduate Certificate in Education (PGCE) programme at the local pedagogical training institute. Trainee teachers are required to reflect on and review their existing physics content knowledge during the process of acquisition of pedagogical content knowledge. As a result of the firmly held teaching belief and misconceptions about certain physics concepts, the physics content knowledge of the trainees are problematic. This paper makes an attempt, through the case study of a pre-service physics trainee, to evaluate a teacher professional development (TPD) model whilst critically examining the learning and teaching journeys of that trainee. The data constitute illustrative insights on some physics concepts from her continuous assessments and final examination. The TPD model shows potential in improving content and pedagogical content knowledge of the trainee which nevertheless need to be nurtured for effective teaching and learning.

Introduction

It is not a surprise that physics is considered as one of the most difficult subjects and is feared by many students at the lower secondary level (age 12-14) in Mauritius. Consequently, many of them would simply not opt for physics at the upper secondary level (age 15-18). Research has established that students experience considerable difficulties to develop conceptual understanding of physics concepts (e.g. Monaghan & Clement, 1999). Since, the Mauritian mainstream secondary educational system is too examination-oriented (Bah-lalya, 2006), students learn concepts by rote (Pell et al, 2010; Ramma et al, 2015) to pass their examinations. There is an array of literature (e.g. van Zee et al, 2001) which emphasises considerably on the fact that rote learning restricts students' ability to display adequate cognitive strategies to perform appropriate tasks independently. What is striking is that most students have the firm conviction that rote learning will be rewarded as examination questions can be successfully attempted merely by rote application of problem solving heuristics (Elby, 1999).

Research is continuously stressing on the fact that the type of instructional strategies (Roth & Roychoudhury, 2003; Akanwa & Ovute, 2014) is a determining factor in the development of conceptual understanding. On the other hand, Zhu (2007) and Sobel (2009) emphasise that rote learning does not induce conceptual understanding in learners. Actually, it limits students' ability to reason thereby severely impinging on students' self-motivation and ability to effect conceptual change (Palmer, 2005).

Research also shows that students harbour naive ideas or misconceptions (Richardson, 2003) which compete and co-exist with the correct notions. Such interference can become a source of perpetual conflict (Kennedy, 2016). Conceptually-based instructions should allow students to become aware of the misconceptions and free them gradually of these misconceptions. Kocakulah & Kural (2010) argue that misconceptions are dislodged gradually and not at one go. On the other hand, van Lehn & van de Sande (2009) clarify that "misconceptions don't ever die, they just get beaten in so many situations by confluences that they retire" (p. 366). Moreover, Brown & Clement (1989) advocate that teaching not based on what the learners already know is deemed to fail as learning will not be meaningful.

Pajares (1992) states that the experiences at the school serve as a basis for pre-service teachers who enter the field of education. Most of them have established a bias account of teaching on the premise of apprentice of observation (Lortie, 1975). In other words, pre-service teachers believe that they should teach as they were taught. A pre-service teacher who was taught using the traditional method would hold an absolutist view of teaching and may have difficulty learning to implement a constructivist instructional model (Harkness, 2009).

Teacher professional development model

Research (Leinonen et al, 2013; Grangeat & Hudson, 2015) suggests that professional development course is one of the most influential means that exerts the greatest influence on pre-service teachers to realise, reflect, reconsider and refine their disposition towards teaching and learning. Such a course provides opportunities to demystify the traditional instructional model, based on the behaviourist paradigm, towards the socio-constructivist one where opportunities are provided for inquiry and for trying and testing new pedagogies within a collaborative environment.

The teacher professional development (TPD) model (Ramma et al, 2017) which consists of a series of layers (Figure 1) has been adopted and evaluated in the professional development journey of a physics trainee teacher. The model encompasses lesson delivery through reflection, incorporation of research findings into lesson conceptualisation and, finally, improvement or review of content knowledge (CK) and pedagogical content knowledge (PCK).

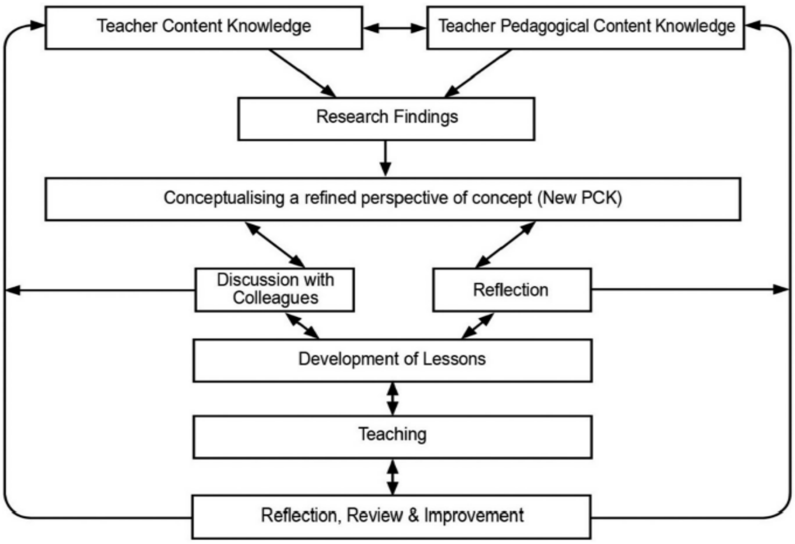


Figure 1: Teacher professional development (TPD) model

Research question

The following research question guided the study:

How effective is the teacher professional development model in influencing a trainee teacher's learning and teaching journeys in physics, and also in supporting her progression in her professional development growth?

Methods

We report a series of episodes of a graduate physics trainee student who embarked on the Post Graduate Certificate in Education (PGCE) full-time programme (1½ years) at the local pedagogical training institute through a case study approach for the evaluation of the TPD model.

The case study approach provides occasions to account for the engagement of the pre-service teacher in a learning situation, the type of analysis and strategies she employed as well as the outcomes that emanated thereof. Viewed through the lens of the TPD model, the case of the pre-service teacher allowed the researchers to understand the research-based pattern (Stein et al, 2000) of content and pedagogical content knowledge.

One of the objectives of the case study was to develop understanding of the nature of physics tasks and how her cognitive demands, which evolved during the lectures, were evidenced by her responses in the examination questions. Further, an attempt has been made to develop understanding of the trainee's cognitive development and of her ability to display aspects of critical thinking in her arguments.

The episodes encapsulating the case study relate to the following:

(i) The module "Subject Didactics II (Teaching and Learning of Physics II)".

The module comprises the following components: misconceptions and conceptual change, concept mapping and concept cartoon, project-based learning, practical work and assessment techniques.

(ii) Continuous assessment (weightage: 30%).

Continuous assessment consisted of two tasks: In the first one, the students had to submit a reflective task on learners' (age 14-17) misconceptions of physics concepts, including mathematics-related connections in one of the four areas: Newton's Law of gravitation, Work done, Electric field of a point charge and Faraday's Law of electromagnetic induction.

Elaborate written feedback was provided on the submitted work to enable the trainee teachers to proceed with the second task. Thus the second task consisted in making use of the feedback obtained from the first task to prepare a peer-micro teaching lesson of the same concept for about 15 minutes. The aim of this exercise was to further guide the trainees in their professional development journey and to expose them to bodies of knowledge relevant to teaching and to connect them to actual teaching (Kennedy, 2016).

(iii) Examination of the module (weightage: 70%).

The examination consisted of a 2-hour paper related to pedagogical content knowledge and the trainees were required to answer 2 out of 3 questions. The first question required the trainee teachers to demonstrate knowledge and competencies of physics and mathematics (integration of mathematics in physics) for the teaching of 'projectile motion' to students of Higher School Certificate level (age 16-17).

Questions 2 and 3 also required the trainee teachers to describe appropriate pedagogical approaches intended for learners (age 16-17) to develop conceptual understanding of the concepts 'work done' and 'simple harmonic motion' respectively.

Participants

Five pre-service trainees were enrolled on the programme and two of them had dropped out of the course after one semester given that they had taken jobs in areas other than teaching. Among the remaining three trainees, only one of them agreed to participate in this study. The case study relates to the teaching-learning journeys of that particular trainee teacher.

Ethics

Informed consent was obtained from the trainee regarding her voluntary participation in the study. She was reassured that all information gathered would be treated confidentially and that she would get access to the data and that she may withdraw from the study at any time.

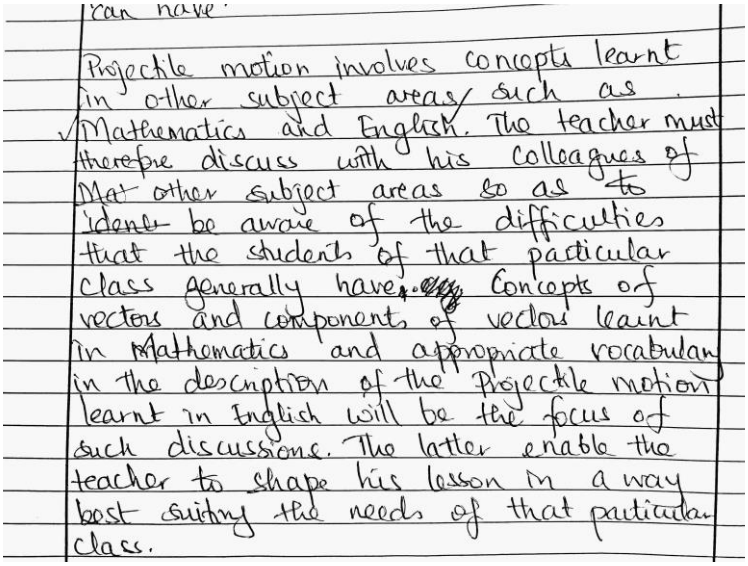
Findings & Discussion

Taking into consideration the space limitation in this paper, we are reporting on the continuous assessment and examination performances of the trainee in relation to content knowledge (CK), pedagogical content knowledge (PCK) and critical thinking which permeates across CK and PCK.

The trainee attempted question 1 (projectile motion) and question 2 (work done). She scored Grade A in this module.

Content knowledge

The trainee teacher demonstrated awareness of linkages with different subject areas like mathematics and English to achieve the intended objectives for teaching projectile motion.



can have.

Projectile motion involves concepts learnt in other subject areas, such as Mathematics and English. The teacher must therefore discuss with his colleagues of ~~Mat~~ other subject areas so as to ~~iden~~ be aware of the difficulties that the students of that particular class generally have. Concepts of vectors and components of vectors learnt in Mathematics and appropriate vocabulary in the description of the projectile motion learnt in English will be the focus of such discussions. The latter enable the teacher to shape his lesson in a way best suiting the needs of that particular class.

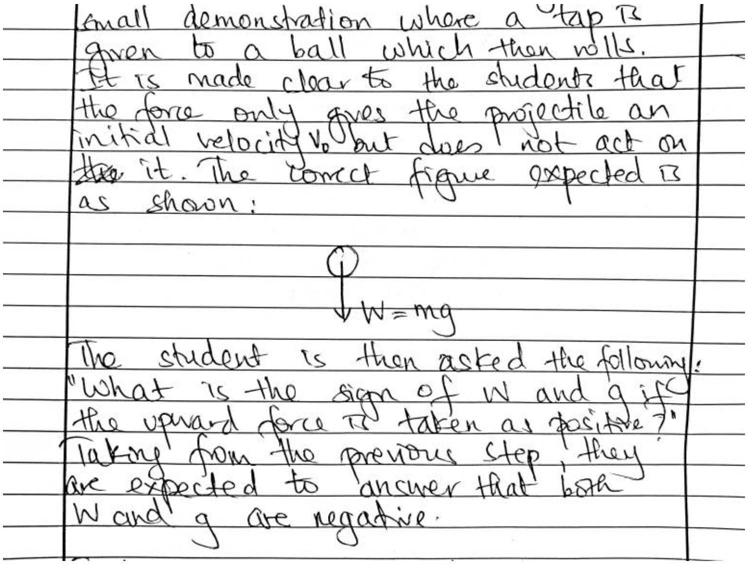
Figure 2: Trainee teacher knowledge of integration

As shown in Figure 2, connection between the motion of the projectile and vectors as well as components of vectors learnt in mathematics has been made. There is also evidence of bringing to the attention of her students that the magnitude of the velocity vector is employed in the calculation of the horizontal and vertical components of the velocity.

It should be highlighted that her statement about integration with mathematics could be traced back in the continuous assessment tasks whereby she related with examples the concept of radioactive decay with mathematics concepts such as probability, functions, exponential and logarithmic graphs. In her write-up, she explained the importance of such integration since “mathematics clearly plays a highly significant role in ensuring the proper grasp of the concept of radioactive decay”. She further explained that the inability of the students to translate concepts from one subject area to other, in this case from mathematics to physics, leads to “a misconception cycle”, reference is made here to ‘*Research Findings*’ of the TPD model (Figure 1).

For the ‘work done’ problem (Question 2), the trainee teacher rightfully adopted a non-linear approach in her argument. She explained how she would guide her learners to recall about related physics and mathematics concepts. She further provided diagrammatic representations of forces acting not only in the horizontal, but, also, in the vertical direction, despite the fact that the net force in the vertical direction was zero. This is an example of a situation that would help her students to ‘think out of the box’ as it represented a counter example of ‘no work is being done’ in the vertical direction.

Though she holds mastery of physics content knowledge, she still withholds misconceptions in certain areas of physics. Research on prior knowledge (Falk & Dierking, 2000) suggests that most knowledge structures are firmly held making them very resistant to change and this eventually leads to robust misconceptions. Long and dedicated professional development courses and curriculum reformulations (Leinonen et al., 2013; Jordan et al, 2017) are needed for novice teachers to dispel the misconceptions.



small demonstration where a tap is given to a ball which then rolls. It is made clear to the students that the force only gives the projectile an initial velocity v_0 but does not act on it. The correct figure expected is as shown:

The student is then asked the following: "What is the sign of W and g if the upward force is taken as positive?" Taking from the previous step, they are expected to answer that both W and g are negative.

Figure 3: Misconceptions

From Figure 3, we present evidence of firmly held misconceptions concerning force and motion. The trainee teacher explained that "… the force only gives the projectile an initial velocity v_o …" and "… the upward force is taken as positive". It should be highlighted that for the second situation, since no mention of air resistance has been made, then the notion of an upward force becomes ambiguous and may create confusion in the minds of learners. These cases challenge teacher educators in professional development courses in their journey to guide trainees to identify misconceptions and to dislodge them. Teacher educators need to help novice teachers to think analytically and relate knowledge and procedures to the type of problems they will actually face (Kennedy, 2016).

The TPD model creates the pathway for trainee educators to contextualise misconceptions within problem situations while having recourse to research findings. Thus the model in its cyclic mode, in the long term, encourages the novice trainee teacher to engage into systematic reflection and analysis of his/her conceptual understanding with a view to exacting plausible solutions to a variety of problems of practice (Kennedy, 2016).

Pedagogical content knowledge

To improve her confidence in teaching in a mixed-ability class, the trainee teacher realised that collaboration with colleagues from other subject areas is crucial "to shape his [her] lesson in a way best suiting the needs of that particular class". It should be emphasised that the collaboration element adds value to the integration of knowledge within and across subject areas. This collaborative endeavour, as highlighted by the trainee teacher in her continuous assessment task on radioactive decay, provides "learners with the necessary data that will urge them to question their prior knowledge, misconceptions and physico-mathematical constructs…". Such an approach is in line with the '*Discussion with Colleagues*' item of the TPD model.

In her answer, she further suggested that the teaching of projectile motion can be effectively approached by guiding learners to "trace out the path of the projectile… [during] a video viewing [session]… at equal time interval". The trainee teacher, thus, made the link between the visualisation of physics concepts using videos and her teaching strategies in a constructivist setting which include scaffolding and discussions.

Moreover, from her answer, the trainee has demonstrated a reflective attitude (Le Cornu & Peters, 2005) in conjunction with the TPD model in her discussion on the inter-relationship of differentiated instructions and formative assessment. She elaborated on the formative assessment task with regard to the 'work done' question by suggesting to engage her learners, through questioning and hands-on activities, to experience friction in a variety of contexts. From her answer, there is sufficient evidence that would justify her ability to stimulate critical thinking among her learners. There is a lot of focus on making connections of content knowledge with real life situations and also on verifying and validating assumptions instead of relying solely on declarative knowledge. This is, in turn, a clear indication of the trainee's critical and reflective dispositions with regard to the *Reflection* item of the model.

Conclusion

This case study examines the teaching-learning journeys of a physics trainee teacher through the lens of the Teacher Professional Development model. The model has been effective in bringing a positive change in her engagement in the *Subject Didactics II – Teaching and Learning Physics II* module and also in her academic performance. There is clear indication of the trainee's commitment to improve content knowledge and pedagogical content knowledge alike while critical thinking is infused in both. As far as critical thinking is concerned, the evidences obtained from the continuous assessment and examination scripts reveal that the trainee has developed the ability to argue and justify her propositions in a constructive manner. For instance, in the 'work done' question, she has broken down the problem into segments and set questions to guide her learners in identifying all the forces acting on the system. Concurrently, the researchers have been able to relate the trainee's professional growth with the items highlighted in the model. Nevertheless, despite showing sufficient growth in her transformative practice, she still holds misconceptions in certain areas of physics and that frequent and rigorous reflection are needed to supersede them during continuous professional development courses.

However, the enactment of the TPD model (use of research findings, collaboration and refinement of PCK) was studied in one instance of the trainee's professional development. The model, being cyclic in nature needs further exploration across different areas of the trainees' learning and teaching journeys.

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SCIENCE TECHNOLOGY ENGINEERING MATHEMATICS (STEM) LAND: FOSTERING RESPONSIBILITY IN LEARNING IN RURAL SCHOOLS

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Is it possible for adolescents to take responsibility for their own learning? How does a free progress system where children make choices about what they want to learn and how (within a given framework) impact this sense of responsibility? Would the need for self-direction result in renewed engagement from children or would it lead to children feeling lost? Would such an environment result only in individualist learning or can interventions based of values support the creation of collaborative learning community with rich peer-to-peer and group learning? This paper offers a case study of a rural STEM center (called STEM land) that attempts to answer these questions with 7th to 9th graders. It examines some of the challenges and interventions that supported the creation of the culture of learning. It offers various examples of learning as a social activity, deep learning, art, reflective spaces as well as academic performance. It also offers an insight into how the essence of this learning culture could be replicated with much younger children from 3rd to 7th grades in a different school.

Context

We are a team of engineers who teach and are presenting our observations in rural STEM centers run in two outreach schools of Auroville – Udavi School and Isai Ambalam School. Both schools aspire towards holistic development of the child and the managements are progressive. The children attending come from villages surrounding Auroville.

Udavi School follows state board syllabus and we work with 47 children from 7th to 9th intensively for 6 hrs/week for all their Mathematics (Math) classes. Isai Ambalam School follows the central board syllabus and we work with 48 children from 3rd to 7th grades intensively for 6 hrs/week during the Environmental Sciences (EVS) and Math classes. In demographics, the occupation of parents in both schools is unskilled labor (35%), skilled labor (55%) and salaried workers (10%). The predominant community accessing Udavi School is MBC (Most Backward Caste) and accessing Isai Ambalam School is SC (Scheduled Caste). The primary focus of this paper is our work at Udavi School.

The villages around Auroville are very close knit in caste and family structures which also results in segregation of living spaces. The schools allow for spaces where children from different communities are together. Alcoholism and its related problems are predominant in the villages. Many children come from poor and dysfunctional families. About 40% of the children have access to an evening center where they get support for homework or exposure to activities.

The name STEM land is in reference to Papert (2002) Mathland as places where children would learn Math naturally.

Philosophies underlying stem land

The philosophy underlying the approach for STEM land is based on the principles of progressive and constructivist thinkers like Jerome Bruner in the United States, Sri Aurobindo and Mukanda in India and many others briefly described here. Constructivist Education Theory (Bruner, 1960) indicates that knowledge is not delivered into the learner (whether child or adult) but recreated by the learner on his or her own. Children actively construct their knowledge by connecting new knowledge to what they already know.

In India, Sri Aurobindo (Aurobindo, 1910) says that nothing can be taught, but the teacher can guide, support and encourage a child in the process of learning enabling them to evolve towards perfection. More recently, Mukunda (Mukunda, 2009) describes the three aspects of learning that are relevant to schools – conceptual knowledge, procedural knowledge and higher order reasoning. Conceptual knowledge (and change), she states, greatly benefit from constructivist approaches.

Taking a specific aspect of STEM for Maths, the National Curricular Framework (NCF 2005) (Pal et al, 2005) states that the 'useful' capabilities relating to numeracy, number operations, measurements, decimals and percentages are only a narrow goal of Maths education. The higher purpose of Mathematics, it says, is Mathematization: the understanding and application of mathematics in different situations with a focus on abstraction, patient problem solving and logical thinking. Meeting this goal requires a fundamental change in the approach used in schools. It requires classrooms to move away from simplistic 'sums' to more complex problem solving and contexts. It requires a shift in conversations in the classroom from the 'right answer' to considering and discovering approaches to problem solving. In a similar fashion NCF treats the development of scientific inquiry as more important than the knowledge of scientific facts.

The constructionism theory (Papert & Hare, 1991), adds to the constructivist theory the belief that children construct their own knowledge best by creating something outside their minds that is often shareable both physically as well as virtually. This highlights sharing as an interesting aspect of learning as is and the role of peers. While this appears at odds with radical constructivists (Cobb, 1994) it completes an essential aspect in the learning process of children for social interactions and the richness of the learning environment. Further research has worked on creating classroom environments that engage children in collaborative practice and is further elaborated specifically through inquiry (Goos, 2004).

Emphasis on the social aspects of learning is predominant in most alternative schools, and particularly emphasized in democratic classrooms and schools that bring democratic values to education. It can include self-determination within a community of equals, as well as such values as justice, respect and trust (Waghid, 2014; Apple & Beane, 2006).

Values form the essential basis of actions and are required for the improvement of the social aspects of learning and forming a learning community. However, 'teaching values' has often had its limitations. The exploration of inner capacities through leadership tools (Sharma, 2006) has the potential for transforming reactions of fear into conscious responses based on inner potential and to transform group dynamics to be more humane and respectful (Tim et al, 2003). LIAP (Leadership in Action Programs) are leadership programs are based on actual application to real life problems rather than a role designation. It is the development of leadership practices and behaviors through individual and group reflection with the goal of creating new behaviors and mindsets. The impact of LIAP is explored in this research.

Further beyond the skills, competencies and societal aspects education is the development of the child as a whole. 'The progress of the child guided by the soul and not subjected to habits, conventions and preconceived ideas is illustrative of a system of free progress' (The Mother, 1956).

At STEM land, our goal is to develop the values of responsibility, equality and the courage to create in children. The implications of following such a philosophy, its challenges and some results are presented in this paper.

Activities and interventions at STEM land

STEM land is a dynamic space that is constantly consciously responding to the learning needs of students, facilitators and youth. Here is a glimpse on how things work:

Circle time

When students come in for their Math classes there is a circle time. This allows everyone - students, facilitators, volunteers as well as youth who come in to learn electronics and programming to start the session together. Other than announcements anyone can share or bring up an issue in the circle and it often has updates on what individual students or groups have been working. An example of an announcement would be the creation of a reporting notebook to share if something was broken or needed purchasing. While very broad ground rules of respect yourself, respect others and respect materials were agreed on in STEM land further detailing of this happens as an issue or need for organization comes forward e.g. a child brought up that there should be an agreement that laptops need to be signed up before being checked out for use, or that no food should be eaten inside. Most of these agreements are reached quickly and followed by all, including facilitators.

It was through these discussions that the children arrived at the learning rules of learn something new, learn something old and learn something now. While new represents the various hands on activities, games, puzzles, etc the now represents what is there in their Math curriculum that they are expected to learn as part of the state board syllabus. The old represents gaps in learning that they identified as they were learning something new and now.

Multi-grade classroom

There are multi-grade classrooms for one or two sessions a week where there are around 40 students from higher and lower grades together. There is significant peer learning and sharing of what one has learnt. Students have learnt both hands on activities such as soldering, robotics, programming, games and puzzles as well as academic aspects such as number systems, practical geometry from each other. It is not younger students who learn from elder ones and anyone who has spent enough time in mastering something shares it with others. Youth from the villages often come in and learn from children programming and hands on electronics. One of the challenges in multigrade classroom is space and effective circle time as well as limited resources such as laptops. But, such challenges are usually got around by working in groups.

Project presentations

Further into a term once a week there are project presentations where students share the projects they created in Scratch 2 (Resnick et al, 2009), Alice 3, etc. This inspires other students to create similar projects or build on what is presented. It was hard to manage time for project presentations and it brought in a system for the presentation to be completed in 5 minutes with 5 minutes for interaction. This has helped children improve their presentation and organization skills as well as manage time. It also gives a need to be accurate and rigorous in what they present and aids in their own understanding and retention of ideas and concepts (Ranganathan et al, 2015).

Additionally, as children are all working on different areas it gives a chance to be exposed to new concepts or reminded of them.

Weekly puzzles

We introduce activities e.g. the weekly puzzle that creates conversations about mathematical challenges. There are no prizes for solving puzzles and both those who attempted and those who completed are acknowledged. It has been noticed that though children engage in conversations with each other over puzzles no child has copied the solution from another to claim as their own.

Plans and tracking

Children do not all work on the same concept, chapter or project. They plan their goals every week and also track their work both at STEM land and at home. Children also document how they felt after their weekly assessments and what they will do different the next week. These are reflective practices that we have put in place for children to learn to plan and track their progress. The first year this was done using spreadsheets, however, it took children a lot of time to type, there were also errors with managing the formatting in the spread sheet and it was cumbersome to track each day. In the second year, a software helped them track this information in a database with quick entry for their academic goals. The plans for all the children for a week are displayed to support collaborative and peer learning.

Assessments

There are weekly assessments that have 3 stages – novice, intermediate, expert that supports students understand their skill level. The students can close their notebooks and have conversations about the content. This encourages abstraction and conversations about the topics through collaboration.

Material accountability

The responsibility of taking care of the material at STEM land has been taken care of by children splitting the task of checking everything is in order. At one point a wooden ball from one of the games was lost. Unable to find another quite like it the students 3D printed the piece and painted it with nail polish to make it look like the original

LIAP (leadership in action programs)

One of the challenges was that not all children found themselves able to cope with the freedom given to them. A few felt that they needed continuous support from facilitators or peers and a few got carried away with this and frequently played games and did not meet their goals. We organized a leadership program that looked at aligning who I am (what I care about), the systems and patterns of the society and what I do. This was followed by triads which are reflective spaces where 3 children and a facilitator meet and share what they able to do over a fortnight.

Here are some reflections from the children shared at triads with facilitators:

Student 1: *"The game we were playing as a group during lunch hour is very physical One child was unwell and was being forced to play the game by the group with the threat of being excluded from further games. I decided not to participate in such a game as I stand for caring."*

Student 2: *"There is no specific organization of mouse in the box to keep it. It is being put back haphazardly and gets tangled and the mouse is going bad. I would like to organize the box".* She organized a system where she made partitions in the box and labeled each of the partitions so everyone knew where to put them.

Student 3 noticed many gender biases that we hold in our society and how it took her and her mother courage to allow her to be involved in a workshop from which she came home later than usual

We hope that the ability of children to notice culture, social patterns and reflecting on them will help them notice and address social issues that we face as a society as they grow up.

Observations of learning as a social activity

When learning becomes a social activity, it spreads effortlessly starting from one initiator and soon covering a large number of children. Here are some examples:

Rubik's cube, games and puzzles

In our hope to teach through inspiration we attempted to build a robot that could solve the Rubik's cube. Our progress was slow and tedious. The children asked us what we were trying to create and we showed them a video of a robot solving the cube. The children were extremely inspired watching the video and tried to solve the Rubik's cube by themselves. They could not solve it at first. Later, they solved the Rubik's cube using an instruction manual. This became a social activity with many children learning strategies and formulas from other children. Over 20 children we work with can now solve the

Rubik’s cube without looking at the instruction manual Among them, 10 students can solve it within 2 minutes and 1 student less than 1 minute. The way the activity grew made learning a social activity and was replicated in many other aspects of their work.

Playing and learning strategies in the games and puzzles in STEM land have similarly spread without one-on-one inputs from facilitators. The children have also started an activity of putting up their favorite games and puzzles as a part of challenges in the school fair adding an intellectual dimension to the school fair.

Sets game

One of the volunteers had an interesting game that helped children learn some of the fundamental ideas about sets. The setup of the game required a couple of hidden rules about two sets (e.g. one set of blue shapes and the other set of rectangles). Then we drew the Venn diagram and the children guessed a shape and its color in each section till they were able to figure out the secret rules. He gave this game to a small group of students, but within two or three days most children had mastered it and were then able to link it to concepts of intersection, complement within set theory.

Deep learning: ability to apply concepts learned

A couple of the letters in a display that blinked ‘STEM land’ using 7-segement displays made by students a year back were not functioning properly. Two children in the 7th grade expressed interest in fixing the display. A facilitator walked them through how powering a leg of the display lights up one of the 7 segments similar to an LED (Light Emitting Diode). They were fascinated by being able to understand and fix something and did so over a couple of classes. After fixing the board one of the two was interested in doing something more with the Arduino.

He wired up the 7 segments to a separate Arduino pins to control the segments individually and managed to write his first program in ‘C’ to display a 1 by the end of a class. He was provided an inputthat the code will soon get out of hand if he did not start organizing the code (in a language he was learning) into functions.

The next day, he came by during lunch and asked to be shown what these ‘functions’ were. When he was told that they similar to blocks in Scratch, his face immediately lit up and he said, “*Well I understand blocks.*”

He had an activity class after lunch and he sat down to implement what he had in mind. He ran into a couple of syntax errors, but then worked on his own for 45 minutes. In this time, he had made a single digit counter that incremented from 1 to 9 every second. He then asked for ideas on extending the functionality to make a clock out of the Arduino. After a conversation, he added a second 7-segment display to get the second digit of the clock he needed. He even managed to figure out the logic of the first digit continuing to run when the second was implemented to create a 99s counter.

We feel that taking a concept of a blinking LED, extending it to fix a 7-segment display, to controlling individual segments and putting it all together to make a 60 s clock with very little help from an adult is a good example of deep learning.

STEM to STEAM

The children made many projects to demonstrate their learning and used these as presentations for other children to learn concepts. Some of these were remarkably detailed and artistic. For her presentation one of the children created a project in coordinate geometry that allowed the user to enter points one-by-one and when the picture was complete it became a van (as shown in Figure 1). These projects add a very important element of creativity and art and bring in beauty and inspire the group as a whole to want to create not just projects, but beautiful projects.

Outcomes of 9th grade

At the end of the year we did a survey with the 9th graders to understand what they felt was their achievements of that year in school. 90% of the children were able to point to something specific they were proud of these included projects they had created, being able to solve the Rubik's cube, being able to work independently and in groups, ability to plan their work and track their progress. Many of these were higher order skills and competencies and meant that students believed that what can be learned is more than academic skill. We also found that the academic performance on an average had increased by 7 points from before.

Working with younger children

About a year after starting STEM land at Udavi school we were given an opportunity to create such a space for 3^{td} -7th graders at Isai Ambalam.

As a school, Isai Ambalam faced many challenges and we engaged the children in small real life challenges. This allowed them to take responsibility of their school and surroundings. As an example, the school faced a water issue and the children started exploring and understanding water. They built an instrument to measure the water level of the bore-well and track water depth. They also created an overflow alarm system for the tank to avoid wastage of water due to overflow. The children also felt that the sense of scarcity could be transformed into a sense of abundance if there was a pond and over time they worked over breaks, lunches and eventually stayed over for a couple of days at the school to create a pond. The children of 3rd and 4th grade worked as a team and also learned estimation, areas, ratios in cement mixing, etc while creating the pond.

When the students inaugurated the pond by putting fishes in the pond even parents who had otherwise expressed unhappiness that their children were working with their hands in their breaks and sleepovers and coming home with dirty clothes were thrilled to see what their children had created.

We felt that even though our approach with younger children had been quite different we were still looking at inculcating values of responsibility, equality and courage to create alternatives in them.

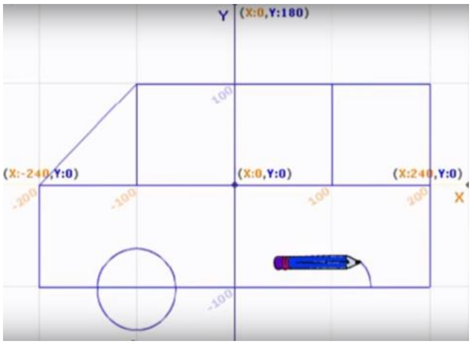

Figure 1: Co-ordinate geometry as an art form.

Figure 2: Pond at Isai Ambalam School.

Conclusions

Children can be responsible for their own learning. The challenges of being unable to handle freedom (and responsibility) can be addressed if the children have access to tools that allow them to work out of possibility rather than fear. This creates an environment based on values where children guide themselves with what is important for themselves, as well as, for society as a whole. Children can learn from each other in an environment which encourages peer interaction and the freedom to explore one's own ideas independently, or to work with peers on projects. When facilitators provide and encouraging and supportive environment without directing all the activities surprising discoveries and demonstrable progress can be made. The opportunity for individual and group reflection further supports children in becoming observers and owners of their own learning.

We have presented a case study in a rural STEM land with 7th to 9th graders where the above resulted not only in individual progress, but also created a collaborative learning community with rich peer-to-peer and group learning. Learning itself became a social activity.

The essence of such a learning environment is values and progress can be seen with even younger children with real life projects if the focus is on developing responsibility, equality and courage in children.

Acknowledgements

We thank Aura Semiconductor Private Limited, Asha for Education and SAIIER for their continuous support to STEM land that made this research possible.

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AN ANALYSIS OF QUESTION-RESPONSE SEQUENCES IN STUDENTS' SPONTANEOUS TALK

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This study is an effort to understand the process of questioning and answering in discourse among students. More specifically we are investigating the dynamics of the question-response process when students are involved in a spontaneous discourse. We claim that questioning/answering is part of a dialectical process in which conflicts arise due to interdependencies between students, as well as between students and the outer world. Questioning drives authentic discussion and the discussion drives the questioning. This process is what we see as one of the defining aspects of the process of doing science.

Introduction

Student talk and questioning has been recognised as an important means of collaboration for learning and constructing knowledge (Barnes & Todd, 1977). Education is a social process that requires much more than individual, isolated students listening, reflecting, and writing (Vygotsky, 1966). In line with a Vygotskian and Freirean perspective (Freire & Faundez, 1989), we believe that students should be engaged in activities and discussions in which they ask each other authentic questions – questions asked out of a genuine curiosity and desire to know. Questioning may give students a sense of ownership and involve them in a meaningful process of inquiry (Biddulph, Symington & Osborne, 1986; Chin & Osborne, 2008; Commeyras, 1995). But not all educationalists agree on the extent to which students should be allowed to raise questions. For example, some say that students' freedom to define their own problems for investigation should be limited by confining their questions to prescribed topics, 'to ensure that student learning is basically in line with content objectives' (Chin and Kayalvizhi, 2002).

Despite recommendations by educationalists, there are reports that the main classroom discourse is dominated by the teacher, with students rarely discussing or asking questions (Barnes et al, 1971; Dillon, 1988). Even if students ask questions, they generally ask recitation or test kind of questions (Postman & Weingartner, 1971; Chin & Osborne, 2008). But a discourse, where students directly address each other and ask questions to each other rather than the teacher, is very rare.

We find it ironic that the research on questioning has focused more on teachers' questions than on students' questions (Chin & Osborne, 2008). Student questioning research has focused on aspects such as: taxonomy or classification of students' questions (Kearsley, 1976; Watts et al, 1997), and how to encourage students to ask questions (Rothstein & Santana, 2011; Harris, Phillips & Penuel, 2012). In India, there is very little recent research on the prevalence of student questioning - we have only found statements of general impressions (Madhu, 2015) and a few case studies that indicate a lack of student questioning, such as those by Kumar (1989) and Sarangapani (2003). But, in student questioning research, there has been a very little focus on understanding the process of student questioning, especially in spontaneous discourse among students with minimal teacher intervention. However, Meyer (1980) and Hintikka (1981), two well known philosophers in the field of questioning, have written in some detail about the question-answer process in the context of everyday discourse and scientific discourse. They have investigated the discourse of question-reply sequences to understand the context in which questions and replies emerge.

Purpose of the study

Our broader research effort is to understand the process of student questioning in science education. Since we have not found many instances of student questioning or argumentation when students directly address each other inside classrooms, we have been observing and recording conversations between students in relatively naturalistic settings outside of their classrooms. In this study, we are trying to understand the dynamics of the question-answer process by analysing two episodes of students' spontaneous talk. More specifically our aim is to understand the factors that shaped students' questions and replies to their questions in this discourse. Studying children's discourse in naturalistic settings can help us understand important aspects of their learning which could be useful in creating authentic contexts for learning in classrooms.

Analysing the question-answer processes in students' naturalistic discourse

Here we are presenting our analysis of two episodes of question-response sequences of student talk we recorded amongst middle school students. The data has been transcribed and analysed using the methods of conversational analysis (Roth, 2005).

Episode 1 - The explicit question: Does the tree have flowers?

The first episode, was from the first session of a three-day science workshop in our Centre in which found examples of students engaging in meaningful discussions and asking each other authentic and investigatory questions, sometimes with little or no teacher guidance. See the larger report for methodological details (Authors, 2017, in press). This episode occurred between six Class VIII girls from a lower middle class government aided school in Mumbai. The discourse, mainly in Marathi, was videotaped as they were standing close to each other around a variegated bhendi tree (*Talipariti tiliaceum*) before they had been told what to do.

As Srushti and Vaishnavi were looking at and handling the leaves on the ends of the branches of the tree, they spoke to each other in soft voices which were not audible in the recording. Then Srushti stepped over to Devki and the following conversation occurred:

15.40 Srushti [directly to Devki]: **झाडाला फुल आहे का?** (Does the tree have flowers?)

15:42 Devki: नाही. फुल कुठे फुल नाहीये. (No. There are no flowers.) [as she looks at the tree from a distance]

15:43 Mohini: **फुल कुठे? (Where are flowers?)** [hardly glancing at the tree, from a distance]

15:44 Mansi: सगळे झाडाला फुले असतात. (All plants have flowers.) [with her back to the tree]

15.46 Srushti: अरे, आहे वाटत! (Hey, I think it [a flower] is there.) [still looking at the tree from a distance]

15:47 Roshni: नाहीये. ([A flower] is not there.)

15.48 Devki: अरे, नाही, नाही, प्रत्येक झाडाला फुल अस्तात नंतर मग फळ येत. (Really, no, no, all plants have flowers and then they turn into fruit.)

15:52 Srushti: हा. असत. (Yes. [All plants] have [flowers].)

15:55 Mohini: आणि बिना फुलांचा झाडा - (But the flowerless plants -)

15:58 Roshni: हे सुरु आहे! सुरु! (Oh there is the suru! Suru!) [looking at nearby Casaurina tree]

16:00 Mohini: हां! (Yes!)

16:01 another girl: ...सुरु...[inaudible]

16:04 Mansi: काय? **(What?)**

16:11 Srushti: **अरे, आहेत के नाही फुले?** (Hey, are there flowers or not?) [to Vaishnavi, who has a disinterested expression, as Srushti turns to look towards the tree]

16:13 Mohini: नाही शपथ. केस खराब झाली. (I swear there are not [flowers]. My hairdo is getting spoiled.)

16:15 [Srushti pulls Mohini by her hand towards the tree - Mohini makes a complaining expression.]

16:16 Srushti: घरी जाऊन टीवी बगन अपेक्ष हे चांगलं आहे! (This [workshop] is better than going home and watching tv!)

16:18 Mansi: बग न. (see it.) [without enthusiasm]

16:20 Srushti : **आ इकडे ये ना. हे फुल आहे ना**? (Hey, come here. These are flowers, no?) [to Mohini, pulling her by the hand]

16:22 Mohini: काय आहे? (What is it?)

16:23 Srushti: **हे फुल आहेत**, **ना**? (See these are flowers, no?) [showing closely]

16:26 Srushti: परत इथे पान आहेत (There are leaves here as well) [as she takes hold of a branch]

16:29 Mansii: **कुठे आहे फुल**? (Where is the flower?) [Srushti, Mohini, and Mansi all look closely at a branch, pulling the leaves apart to see the bud]

16:31 Mohini: [clicking her tongue to mean no] येत फुल आहे कि छोटी छोटी पान आहेत......(This is not a flower - these are small leaves…....)

16:33 Roshni: पान आहेत ती. (They are leaves.)

16:33 Mohini: ...छोटी ... (...small...) [inaudible]

16:40 Mansi: **ए देवकी ती फुल आहेत ना**? (Devki they are flowers, right?)

16:42 a girl (Roshni?): ये पत्ता है. (This is a leaf.)

16:46 another girl: पत्ता है. ([It] is a leaf)

16:56 a girl: हां, पत्ता है... (Is leaf…)

17:06 a girl (maybe Mansi): **ये पाना है ना**? (This is a flower, right?) [asking the teacher]

17:06 Srushti: फुल आहे (It's a flower.)

17:08 Devki: छोटी छोटी पान आहे. (It's a little tiny leaf.)

17:08 Roshni: पान आहेत. (They are leaves.)

17:08 Teacher: हम्म्म्म (Hmmmm) [from the tone, this sounds like an ambiguous yes]

In this conversation there appear to be two main questions under consideration by the girls, and they may be shifting between these two questions. The question which Srushti initially asks Devki is probably whether this tree has flowers, or whether this type of tree is a flowering tree. The other question is whether the buds that look like flowers are really flowers. It is clear that this is the question in Srushti's mind when she tries getting other girls to closely observe the buds.

Srushti first verbalises her question loudly to Devki. But why did she go and ask Devki? It may be because she wanted to verify that Devki has a certain authority. Meyer (2010) has suggested that verifying authority (rather than getting an answer to the explicit question) is the aim for some kinds of questioning. Some questions can be answered to the satisfaction of the askers if the authorities answer by imposing themselves as authorities, even if they do not provide satisfactory answers with logical reasoning or evidence. If this was the case here, then even if Devki did not provide a rational answer with evidence, she may have been able to verify her identity as an authority and this may have provided some sort of satisfaction to Srushti - which could bring her problem to a satisfactory end. Alternatively, even if Srushti was not satisfied by Devki's answer, she may have been so dominated by her authority that she could not bring herself to question it.

We suspected that Srushti may view Devki as an authority because Devki was one of the 'toppers' in the class, she was talkative and outspoken, and she was also physically dominant (much taller than the others). Although none of the girls were 'upper caste', Devki was from a slightly higher caste than most of the other girls, including Srushti and Vaishnavi.

But actually Devki gave a simple, direct answer: "No. There are no flowers." The way she phrased the answer makes it clear that she interpreted the question as referring to this particular tree, not this type of tree. She also treated the question as if it was a Yes/No question which could be answered in this simple and definitive way. If Shrushti and the other students accepted her as an authority, they may have been satisfied by this answer, even though she did not give any explanation, reasons, or evidence. Or, if they were dominated by her authority, they may not have dared to question it. However, we do not see this happening. The other girls were not satisfied with this answer, and they voiced their questioning.

At 15:48, after Mansi argues that every tree has flowers, Devki changes her earlier reply of 'no' and agrees that all trees have flowers. She also adds the point that flowers turn into fruit, which provides further evidence, since they all might have observed fruit on trees. Devki did not just treat Mansi's statement as something requiring a simple Yes/No agreement or disagreement. Rather than saying, "Yes, I agree.", or just repeating what Mansi said, she built upon it. So a reply from one student guided the other to analyse, further develop, and verbalise the argumentation. Devki's statement that all trees have flowers reinforced Srushti's questioning, making it more possible that if all trees have flowers, this tree also has flowers, and the buds she saw may actually be flowers.

However, Mohini does not agree and at 15:55 argues that there are flowerless plants as well. Here she may not be sure about her reply, she may be wondering and thinking out loud. But building upon Mohini's reply, Roshini brings in an example of a flowerless tree, which the students had observed a few minutes earlier, just next to the bhendi tree.

With Roshini citing the example of flowerless trees, the deductive argument, that every plant has flowers and therefore the tree in question will also have flowers, became questionable. It is an example of how in doing science, deductive arguments are not really independent of inductive arguments. There is a dialectical relationship between inductive and deductive argumentation. By this we mean that induction and deduction are opposing aspects which are inherent to the unity of their relationship in the argumentation process.

With this, Srushti again starts doubting whether the tree has flowers, indicating that she was probably convinced by the argument she heard, that some trees have flowers and some don't. So we can see Srushti continuously challenging her beliefs. This is what we expect from student questioning -- challenging and questioning of one’s own beliefs.

Figure 1: The stipules resembling flower buds

Srushti continued to ask other students to look at the buds more closely in order to answer her question. Her persistence indicates a challenge to Devki’s authority. Her insistence on direct observation indicates that she did not consider this to be a simple Yes/No question. Up to this point Srushti and Vaishnavi had spent much more time handling and looking closely at the leaves than Devki had. And yet, Srushti did not pull Devki to the tree, she pulled Mohini, who seemed to be the one who was least interested and most reluctant (she had just complained about her hair getting spoiled). We do not know whether caste or class differences or some other factors (e.g. friendships, personalities) may have been important here.

Mohini does finally handle the leaves, takes a close look, and then immediately claims that they are not flowers. Rather than just saying that they are ‘non-flowers’ she declares that they are something else - leaves. By stating that they are small leaves (rather than petals), she has also made an implicit distinction between leaves and petals. However, she does not explain why she makes this distinction. It could be that she thinks they are not flowers because she does not see any stamens, anthers, or carpels. But she does not state this either, so we have no way of knowing whether her thinking is really based on observation or on wanting to side with one of her friends.

The tree did have something that resembled flowers (Figure 1). What the students were examining were not petals, but they were not exactly leaves either. The branches of the tree ended in buds which were actually stipules enclosing developing leaves, but they resembled flower buds.

Finally, the teacher is brought into the scene and asked about the buds. Bringing in the teacher seemed to bring an end to the question-answer process, which may have continued longer if the teacher was not asked, and maybe some more and different arguments could have emerged among students. But it seems that Srushti was still not satisfied by the arguments or statements of her friends. It is interesting to note that Srushti does not accept the authority of Devki, the teacher, or anyone else. Perhaps it was because she developed some kind of ownership and emotional attachment with the question; and no authority figure gave reasoned arguments with evidence.

Episode 2 - The implicit question: What size of jaggery pieces would be appropriate for ants to eat it?

This episode is part of a 45-minute session among a group of six girls speaking in Punjabi, sitting and standing around an ant hole to observe the ants. It was part of a session carried out by the researchers with 31 students from Class VIII in a rural government school in Ludhiana District. In the session, students were asked to find ants in the playground of their school, and then using a few different kinds of food items, they were asked to study the ants. We purposely gave these brief and vague instructions so that the students could carry the assignment in various directions. Besides being open-ended, it was also open-beginninged in the sense that the students could define their own questions for investigation. In this episode, we see the emergence of an implicit question:

18:20 One of the three standing girls (not Rupinder): ਏ ਓਹਨੂੰ ਨਾ ਯਾਰ ਤੁਸੀਂ ਭੋਰ ਭੋਰ ਕੇ ਪਾਉਣਾ ਸੀਗਾ! (You should have put it after breaking in smaller pieces!) [While the three girls who are sitting are looking at the ant hole]

18:23 Komalpreet: ਆ ਦੇ.........ਏਨੇ ਪਾਇਆ. (See ... she has put it.) [Komalpreet slightly turns her head towards back and gestures her hand towards Navdeep.]

18:24 Rupinder (to Navdeep (Navi)): **ਨਵੀ, ਸਾਰਾ ਪਾਤਾ?...** (Navi, have you put all of that?) [Rupinder bends down and ask]

18:26 Navdeep: ਨਹੀਂ ... (No...) [as she looks up towards Rupinder]

18:26 Rupinder: ਭੋਰ ਭੋਰ ਕੇ ਪਾਉਣਾ ਸੀਗਾ. (You should have put it by breaking in finer pieces.)

18:28 Nishu: ਓਹੀ ਤਾਂ ਕਰ ਰਹੀਆਂ ਨੇ ! (That's what we/they are doing!) [looking up towards Rupinder]

18:29 One girl (maybe Rupinder): **ਖਾਦਾ ਨੀ ਜਾਣਾ ਉਹਨਾਂ ਤੋਂ.** (They will not be able to eat.)

18:30 Komalpreet: ਉਹ ਦੇ, ਉਹ ਖਾਂਦੀਆਂ ਪਈਆਂ ਨੇ (See, they are eating!) [Pointing her pen towards ants]

18:32 Navdeep: ਹੌਲੀ ਹੌਲੀ ਖਾਂਦੀਆਂ ਨੇ . (They are eating slowly.) [looking up at Rupinder]

Our interpretation of this episode is that it shows the evolution of the (unvoiced) implicit question, ‘What size should the jaggery pieces be?’ Initially, the size does not seem to be in question, as none of the girls voiced disagreement with the first girl that the jaggery should have been put in smaller pieces.

The first girl seemed to be complaining and trying to place blame. Komalpreet tries to claim her innocence and places the blame on Navdeep. Rupinder, who was standing in the back, asks if any jaggery is left, so that it can be put in smaller pieces. She also gives a reason: the ants cannot eat large pieces. This indicates that the girls are probably wondering what is the best size of pieces for the ants, because their aim is to feed the ants. We claim that they have made a hypothesis that the ants are not eating because they cannot eat such large pieces. But then Komalpreet sees that the ants **are** eating the large pieces, contradicting the initial observation and the hypothesis. When Navdeep justifies that they are eating slowly, she may be having a new implicit question in her mind, "How can they eat such large pieces?' Later in the session the students also broke the jaggery into smaller pieces to see if the ants would eat it, in a further test of the same hypothesis.

We claim that the evolution of the main implicit question is based on observations which conflict with beliefs. The initial belief that the pieces should be small probably arose because the students had observed that the ants were not eating the jaggery and that the pieces were large, compared to the size of the ants. Then this belief was brought into conflict with the subsequent observation that ants were eating it, after all. Therefore the question became more prominent, although it was still not stated explicitly.

We find it interesting that throughout the girls' session with the ants (including the parts not shown here), most of the argumentation is directly or indirectly about social relations and power dynamics within the group and between the group and outsiders: who should be where, who should or should not do or have done something, whether someone else agrees. Some of these questions may also be concerning the ants, but there are less of those kinds of questions. The social questions appear often, overpowering the ant questions.

Although we let the students work independently, the power dynamics between students and between students and teachers may have somewhat inhibited the students from getting engaged in meaningful discourse about ants. It was clear that the students were quite concerned about what their assignment was. Although they did ask their own questions and try to find answers, there were indications that they were focussing on figuring out what we, the teachers, wanted them to do. Maybe the presence of the camera also, to some extent, made them act according to what they thought was expected from them.

Discussion

The two episodes of question-response sequences present examples of different types and combinations of confusions, oppositions and negotiations among students. But in both the episodes we see questioning as a crucial aspect of student discourse. According to Meyer (2010), questioning is what drives discourse and communication. Furthermore, questioning was sustained because of conflicts and disagreements, not just between each other but also with one's own beliefs. This aspect of questioning, to challenge others as well as one's own beliefs, we believe is central to doing science and this is what we expect of the discourse in science classrooms to include.

Though there were expressions of power between students and between students and teachers with differing amount of authority, but at times, we see students challenging this authority. In both episodes, students generally did not believe what they were told but instead called attention to counter-examples and showed disagreements with their peers and their teachers. One of the reasons, for such disagreements, could be students' emotional attachment and ownership to the questions and the discourse. The discourse in both episodes was governed by the students. Students took decisions on turn taking during talk, whether a question got answered or not, and whether to accept or reject new questions. We see these as crucial roles for students in classroom discourse.

Another important conclusion is that the questions as well the replies were shaped by the students' observations and interactions with the physical stuff. They did not resolve the questions purely on the basis of abstract reasoning. They were continuously referring back to the stuff for evidence, particularly when a justification for an argument became more controversial or the abstract reasoning did not work. We claim that this is an indication that the students were doing science.

Furthermore, in both the episodes, at a number of occasions, we saw a shift in replies from being 'not questionable' to 'questionable'. Sometimes this shift happened with students bringing examples from their previous experiences and at other times it was a result of their interactions with the physical stuff. This supports our belief that science - including the science that we claim these students were doing - is based on observations of physical reality. Questioning as well as answering in science requires a recurrent concern for physical reality, for the formation of both questions and evidence. Furthermore, we believe that it is more useful to think science as a tentative and probabilistic *process* of doing science, which involves questioning, than thinking science just as a *product,* 'a body of knowledge'.

We also saw the evolution of questioning from being more general to being more specific. For example, in the flower episode, what was initially a general question about whether this kind of tree has flowers became a specific question about whether particular buds were flowers. In the ant episode, the implicit (unstated) question about why the ants were not eating jaggery evolved into a more explicit question about whether they were having trouble eating because the pieces were too large. These shifts in questioning could take place due to the presence of the stuff and its accessibility to the students. From accessibility we do not mean just the availability of the stuff to the students, but also student's realisation that they can handle the stuff. Actual handling by the students was crucial for both the questioning and the answering.

In the two episodes we found that questions may arise gradually or suddenly depending upon the progress of the discourse. The formation of each question was often related to the previous questions as well as to the replies. However we also observed that at times it was difficult to sustain the natural discourse among students as they tried to act, ask and respond according to the expectations of the teachers. This seemed to be a hindrance to their inquiry process.

Students' beliefs and their replies were not just guided by their 'rational' thoughts and observations of physical stuff but also by collective interactions, emotions and social power relations. Efforts to individualise learning, and stifle (or deny the relevance of) social relations may inhibit discourse and the process of doing science.

Although our investigation was aimed at understanding student learning rather than testing a teaching/learning method, our results suggest that students could occasionally be allowed to interact in small groups independently from the teacher, under relatively open-ended and even open-beginninged contexts in which they have some physical stuff to handle. This might encourage students to question and respond to each other. By listening to and analysing their discussions, teachers could find ways to encourage students to continue doing science (and do it more self-consciously and rigorously) in class as well as in their everyday lives.

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ESTABLISHING A COMMUNITY OF PARTICIPATION IN A PRIMARY MATHEMATICS CLASSROOM: AN ACTION RESEARCH

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In a Grade II classroom with 22 students of age group 7-8 years, a teacher constructed this community through her acts of questioning and probing. This paper elaborates on the specific acts of the teacher that helped her students in not only discerning repeating units of patterns in the world around them but to also make sense of other related mathematical concepts such as of symmetry, similarity and perspective drawings. The paper traces how the acts of the teacher were appropriated by her students that led to the conceptualisation of concepts beyond what was intended initially.

Introduction

Mathematics teaching and learning, as understood from the socio-cultural perspective (Sfard et al, 2001), is built on the social and communicative activities that get formed when a classroom itself becomes a community of practice (Lave & Wenger, 1991). It is by participation in such communities that children begin to appropriate and imbibe the epistemological values and communicative conventions of the larger mathematical community Goos (2004). Sfard (1998) elaborates the participation metaphor as a practice in which learning is viewed as a process of becoming a member of a community by acting and communicating according to the norms of a particular community. In the mathematics classrooms, participation evolves by establishing a bond between the individual and the others through discussion and collaboration. Van Oers (2001) believes that usually the process of participation begins when a teacher manifests a mathematical attitude by entailing readiness to deal with mathematical concepts and engaging the class in the acts of reasoning. Such acts, though initiated by the teacher, eventually get appropriated by the students.

Participation is a social experience that occurs in a community. Learning is a result of participation in a community when students engage with one another and with the tasks that they are expected to perform (Ewing, 2007). Further, active participation of students can be inferred when their involvement in the classroom proceedings is considered valuable (Sinclair, 2004). One way of encouraging active participation in a community is by imbibing a probing approach that builds on queries, questions or investigations around mathematical ideas and problems. In this paper, the active participation of individuals (students and teacher) in a mathematics classroom was deemed as a community of participation.

This paper presents an episode, undertaken as an action research, where in a teacher tried to create with her Grade II learners a community of active participation. The teacher wanted to change her non-participative mathematics classroom into a community of participants who co-constructed their mathematical understanding. The paper elaborates on how her learners, while participating in this community, made sense of some concepts that were beyond the teacher's initial intentions. The paper builds on the student-teacher interactions as they engaged in learning the concept of repeating patterns.

Background of the participants

This study took place with Grade II students of a Government school located in the South District Zone of Delhi. The class had a total of 22 students (12 girls and 10 boys) in the age range of 7-8 years. At the time of study, the teacher was a Bachelor of Elementary Education (B.El. Ed.) intern and the session described in this paper are from one of her classes during her internship period. One of the authors (also the researcher) was the mentor of the intern and thus observed her mathematics classes as a teacher-supervisor. Classroom observations done by the researcher made the source of the data.

Before teaching the class, the intern had done several in-depth observations of the school, the classroom and its infrastructure, pedagogic practices of the regular teachers, students and their classroom interactions. Taking observations is a mandatory part of the B.El. Ed teacher training programme as it familiarises the interns with the school ethos, teachers, students and their backgrounds. During these observations, the intern noted that the mathematics classes of her respective grade II children usually followed the drill and repetition method, mostly following the teacher's instructions. She reported about the dullness and non-participative atmosphere that prevailed in the class as the children were often found copying the solutions from the chalk-board with very little initiation on their part. With this understanding of the classroom environment, the intern decided to undertake an action research with the intention of changing the nature of participation. She planned to teach her lessons through a participatory approach by planting questions that would initiate children's discussions, thereby building a community of participation.

The session

The class began with a motive of teaching Grade II children about identifying repeating units in repeating patterns. The NCERT Mathematics textbook (NCERT, 2006) suggests teaching patterns by observing and discussing the patterns found in the world around us. The intern (henceforth the teacher) thus planned to teach this concept by dividing the concept in three graded phases, spanning over an hour.

The task: The objective of the task was to let children understand the idea of recurring units in repeating patterns that exist in the world around them. In the first phase, the teacher showed the class a picture of a street having a repetition of similar looking buildings, pavements, electricity poles and street dividers (Figure 1). The students were asked to observe the picture and identify the repeating units in it. As an extension, the students were encouraged to observe their classroom and look for objects that repeated. In the next activity, the children were taken on a campus walk to enlarge their contexts, moving out from the limited classroom space to a bigger space, such as their school. The intention in the third phase was to let children express their idea of a repeating unit. They were encouraged to draw any repeating pattern that they had come across.

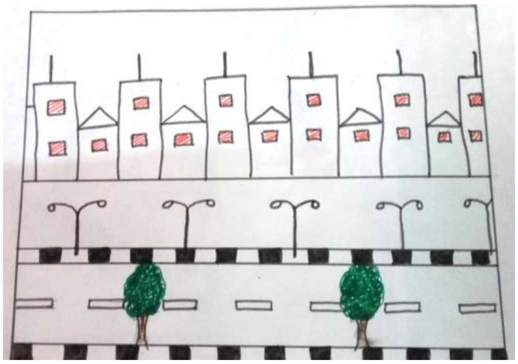

Figure 1

Building a community of participation

Bringing children to participate actively in classroom discussion is a gradual process that begins by establishing a faith in the learners that their contributions can make a difference. In order to build a community of participation, the teacher wanted her learners to speak without hesitation. She took a number of steps to facilitate this. We discuss them in the following sections.

Connecting formal language with informal vocabulary

To begin with, the teacher had to make her students a part of the question asking and answering process. This was done by making connections between the formal mathematical terms and the children's vocabulary. The teacher carefully selected her words and made appropriate connections with children's day to day vocabulary. She gave enough time for her learners to make such connections and waited before introducing the formal mathematical terms.

In terms of repeating patterns, it is essential that the term 'repeat' made sense to the children. The teacher did so by translating the term 'repeat' in the children's native language, that is, Hindi. The verbatim below depicts how an initially non-participative class evolved to the state of participation by such an initiative.

Teacher: (pointing to Figure 1) *Is picture main kaise ghar hain*? (What types of houses are there in this picture?)

The teacher directed the children's attention to the alikeness in the shapes of the buildings. The class observed the picture but nobody responded. The teacher then elaborated.

Teacher: *Is chitra mein kuch aisa hai jo baar baar aa raha hai?* (Is there something in this picture that is coming again and again?)

Here, the phrase '*baar baar aa raha hai*' ('is being repeated in the picture') was meant to communicate the requirement of locating a repeating unit in a repeating pattern. This informal vocabulary initiated a mode of observation that centred on noticing the periodic repetition of shapes. The teacher purposely avoided the usage of formal terms such as repeating unit or pattern to build a confidence in children. This was the first step towards building a community of participation.

In response to the probing, a student pointed to the lines on the top of the buildings (Figure 1).

Student: *Lines baar baar aa rahin hain* (Lines are being repeated)

This response by one student encouraged the teacher to probe for larger participation. She repeated the child's phrase for the whole class to hear and asked them to verify if the observation was correct.

Teacher: *Lines baar baar aa rahin hain...Kya aa rahin hain...?Aap sab dekho.* (Lines are being repeated... are they being repeated...? teacher asks all to observe)

The class agreed and the teacher then pointed to the lines with her finger for everyone to notice. She repeated the statement for more attention.

Teacher: *Yahan par lines baar baar aa rahin hain*. (Lines are being repeated)

The teacher then sought more examples and the entire class got involved. They started claiming about the repetition of electricity poles, black and white boxes on the pavement and squares on the street. They identified five to six such repeating units and associated each of them with the rule of 'repeating again and again'. The teacher spent enough time on every example that was quoted by any child. She repeated the responses by highlighting the identified unit and giving time for the class to think and respond.

Acknowledging disagreements

For any successful two-way participation, it is essential that all the participants have a freedom to express their thoughts. While agreements are easy to establish, a fearless participation is ensured by acknowledging disagreements. To build a community of participation among the teachers and students, it is imperative that the teacher listens and acknowledges her students' thoughts, ideas and disagreements. Our teacher did so by building a feeling of faith in children's observations.

Whenever a student shared a thought, the whole class was encouraged to verify the claim. The learners had to provide reasons for their agreements and disagreements. In case the class did not agree with a response of a peer, the teacher allowed space for the children to provide reasons for their disagreement. The objections shared by a child when her peer pointed to trees as an example for repeating unit reflects this mode.

Student: *Par yeh to baar baar nahi aa raha. Sirf do baar hai.* (But this is not repeated again and again. It's only two times)

Teacher: *Yahan par ped to do hi hain...toh hum kuch nahi keh sakte.* (Here, the trees are only two in number, so we cannot comment anything)

The teacher addressed both the students and tried to build a faith in them regarding their observations. As the picture gave only a synoptic view of a larger area, it was difficult to talk about the recursiveness of the units. This faith established a sense of confidence in expressing their thoughts, thereby initiating a feeling of sharing their views freely.

Introduction of formal terminology

As a subsequent step towards a mathematically embedded conversation, it is important that children use formal mathematical vocabulary in the conversations. Our teacher initiated discussions using formal vocabulary related to patterns by extending the realm of observing patterns from their context to their surroundings. The children were asked to observe their classroom and make note of the things that were repeating.

Teacher: *Kya humari class main bhi aisa kuch hai jo repeat ho raha hai?* (Is there something in our classroom that is repetitive?)

The teacher introduced the appropriate term 'repeat' and hoped to let her learners internalise its meaning. However, as children had seldom been given spaces to share their ideas (noted during the initial observations), the children waited for the teacher to give further instructions. Disappointed by this low participation, the teacher gave a non-verbal cue to the students by pointing to a string that was hanging in the classroom. The string had rectangular sheets of paper stuck on it at equal intervals. This non-verbal cue proved to initiate their thoughts and the children soon made sense of repeatedness by making connections with the repeating structure of the string.

Student: *Rectangles aa rahen hain baar baar.* (Rectangles are being repeated)

We see that the student had inadvertently connected, '*baar baar aa rehen hain*'(is repeated) with the teacher's phrase '*repeat ho raha hai*' (is repeating). She affirmed and asked for more such patterns from their vicinity and then almost all the children started citing examples of repeating units of their classroom. They identified the configuration of the desks, borders in the charts, display boards and switches on the switch board and such. With every example given by the students, the teacher followed the same procedure of repeating a student's response and waiting for everyone to think about it. This act slowly built a participative culture in the classroom. Students were seen using '*baar baar aa rehen hain*' and '*repeat ho rahen hain*' interchangeably while citing their examples.

Reasoning as part of participation

Reasoning, convincing others and sharing thought with others establish the tenets of a rich mathematics classroom. When discussions get supported by reasoning and convincing others on one's observations, it reflects a deeper sense of participation. Our teacher emphasized that her children provided a reason for their claims. The following example supports this.

As part of the second activity when the children were taken for a campus walk, they observed objects that were laid in repeating patterns. A student pointed to the garden fence as an example of repeating pattern, but as this student had pointed to a single object and not to the repeating unit within it, the teacher probed her to explain her thinking:

Student: *Vahan baad lagi hai* (There is the fence)

Teacher: *Baad mein kya hai?* (What can you say about the fence?)

Student: *Usme dandi baar baar aa rahi hai* (Poles are repetitive in it)

Increase in student initiated discussions

As pointed earlier, a community gets established when it imbibes the traits of being a member of the community. Our community of participation was developing gradually and by the end of the second phase of the task, the teacher could trace the traits in students' conversations of being a part of the expected community, that is, of a community that participates freely.

By the second phase, the children had started taking initiations in discussions and could be seen as taking part in all conversations, independent of the teacher. The following conversation clarifies this assertion.

During the second phase when the children were asked to identify patterns in their school building, a child pointed to the collapsible gate (Figure 2) as an example of repeating pattern. This did not convince the other students and they questioned her. The teacher only observed their conversation and decided not to participate in the discussions. The students got involved in reasoning and convincing others by providing logical arguments.

Figure 2

Student 1: *Dekho, is me diamonds hain*. (See, there are diamonds in this)

Student 2: *Acha? Dikha mujhe.* (Really? show me)

Student 1 traced his fingers on the row of diamonds in the gate (◊)

Student 3: *Mujhe aur bhi shapes nazar aa rahi hain jo repeat ho rahin hain*. (I can see more shapes that are repeating in this.)

Student 1: *Kuansi?* (Which ones?)

Student 3: *Yeh dekho cross hain, diamonds hain aur lines bhi hain*. (See the cross here, diamonds and lines also)

Student 3 pointed out the cross (×), diamonds (◊) and lines in the gate with his hands. Simultaneously, Student 2 also figured out another example of repeating units.

Student 2: *Aur triangles bhi hain*. (And there are triangles also.)

Student 4: *Yeh gol gol bhi aa rahen hain* (These circles are also repeating)

Student 2 pointed to the triangles (Δ) and Student 4 had pointed out the round screws in the gate structure.

In all the above conversations, the teacher only observed and listened to her students' examples and reasoning. Eventually, the entire class got involved in this discussion. They could be seen as actively participating and being part of a community that believed in sharing and acknowledging others' ideas.

Extension of mathematical ideas: A by-product of active participation

While the students internalised a gradation in participation, along with, they made a gradation in their mathematical ideas. Their active conversations, embedded in the acts of listening, reasoning and convincing others gave a scope for the development of many related mathematical ideas. Listening to others scaffolded children's thoughts in diverse ways and they could be seen building mathematical ideas related to the concept of patterns. While looking for patterns, the children were also seen to have conceptualised the idea of patterns beyond linearity, symmetry, similarity and perspectives. In this section we quote the instances related to the emergence of all these ideas.

While looking for patterns in the school building, a child noted the arrangement of the square tiles on the floor. She noticed the repetition of squares in both vertical and horizontal directions, showing thereby that she had taken into account the repetition of the tiles in the two dimensional plane.

Student: *Zamin par sab jageh squares hain*. (There are squares everywhere on the floor).

Teacher: *Yeh keh raha hai ki zamin par squares hain...Aap bhi check karo...Aisa hai kya?* (He is saying that there are squares on the floor... all of you should check... is it like that?).

After this example, another child pointed to the iron-grill pattern on the classroom window.

Student: *Yeh dekho, isme design hai*. (See here, this has a design).

Here too, the child had deciphered the repeating unit that appeared at equal spacing in a plane. The identification of repeating units in floor and window grill illustrate that the children had begun observing patterns on a plane, beyond the usual linear way. They were then building the ideas of tessellations and translational symmetry.

Another conversation that shows children's thinking going beyond identifying repeating units was when a group of students noticed the likeness in the shapes of the leaves of a tree.

Student 1: *Is ped ki sab pattiyan ek jaisi hain.* (All the leaves of this tree are alike)

Another child concurred to this observation and also extended it.

Student 2: *Haan, par alag pedki alag hoti hain.* (Yes... but they are different for different trees)

These discussions reveal an understanding of similarity of shapes and the onset of categorisation.

Finally, in the third phase when the teacher asked the learners to draw their observations, one could see the onset of perspective representations of three dimensional objects. Figure 3(a) and 3(b) depict the representation of a stair case from two different perspectives. In Figure 3(a) the steps of the stairs are shown equally spaced in horizontal lines, portraying the top view while Figure 3(b) is a side view representation of the same staircase.

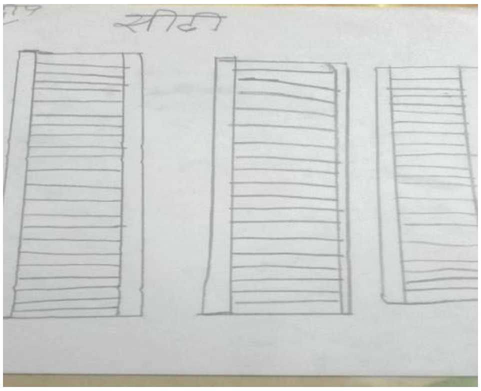

Figure 3(a)

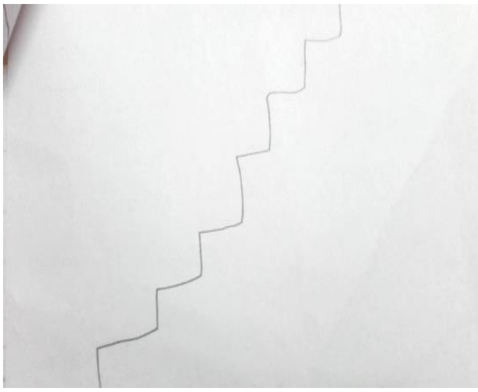

Figure 3(b)

All the above examples reveal that active participation of children can result in an expansion of their ideas. Since children had seen and listened to their peers, they could make mathematical associations that led to the conceptualisation of bigger ideas, beyond the scope of the intended exercise.

Conclusion

In this paper, we have shown how the efforts of a concerned teacher transformed a non-participative mathematics classroom, habitual of copying solutions from the chalk-board, into a community of participants who co-constructed their mathematical understanding. The teacher's specific acts of carefully selecting the vocabulary readily understood by the children, allowing spaces for disagreements, gradual introduction of formal mathematical vocabulary and encouraging children to provide reasoning behind their examples had a crucial role to play in improving their participation. The practices of questioning, encouraging and reasoning, and supporting one's claim with logical argument got established as ethos of the classroom, thereby making the classroom a community of participation.

Building a community of participation wherein children are encouraged to participate also goes a long way in initiating mathematical ideas. In our case, when the teacher built this community, her children got the opportunity to unravel the idea of symmetry, similarity, and perspective drawing which were beyond repeating patterns. One of the reasons for this could be that students held themselves responsible for their learning.

Summarising, when students are given opportunities to participate as a community, they show immense potential in going many steps further in thinking mathematically.

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KNOWLEDGE DEMANDS PLACED ON A MATHEMATICS TEACHER IN LEARNING TO TEACH RESPONSIVELY

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The knowledge of students' mathematical thinking informs teaching practice. Existing research reveals that teachers respond to a reform context through resorting to traditional (Cohen, 1990) or hybrid (Brodie, 2011) pedagogies. In this paper, we report a research study, which attempted to explore and enhance teacher's knowledge of students' mathematical thinking through a systematic study of and reflection on teachers' practice in a reform context. We analyse how a teacher begins to make sense of her students' mathematical thinking as she engages in unpacking mathematics underlying student utterances and is developing deeper knowledge of specific topics. The analysis of a teacher's practice is done through a discussion of paired episodes identified from teaching of the same (sub) topic over two consecutive years. We discuss aspects of teacher noticing and decisions which changed in these two years and analyse the knowledge demands placed on the teacher as she attempts to teach responsively to students.

Introduction

The National Curriculum Framework (NCF) 2005 expects teachers to build on students' existing knowledge and understanding, and therefore recommends moving away from "coaching students for memorisation or transmission of facts". NCF 2005 suggests a focus on processes, meaningful representations, connections, and visualisation as aims of mathematics learning (NCERT, 2006). The reformed curriculum places demands on teachers' knowledge. Teachers have neither through their own schooling experiences nor during training have experienced pedagogies, which are student-centric. They struggle to understand the expectations placed on them through reformed curricula (Takker, 2011) and therefore often resort to traditional (Cohen, 1990) or hybrid (Brodie, 2011) pedagogies. The current discourse in education focuses on training teachers to perform better and become accountable, but does not engage with the questions of supporting teachers deeply (Batra, 2011). Teachers need support in experiencing the content learnt differently, and in developing pedagogies which are sensitive to learners' understandings.

In a reform context, interpretations of teachers become salient to understand the ways in which curriculum is enacted in practice. In a case study of Ms. Oublier, Cohen (1990) reported that although the teacher believed that her practice was revolutionised, the classroom observations showed that her teaching discouraged students' exploration. Although the teacher chooses the content proposed in the reformed curriculum, her ways of dealing with the mathematical knowledge remained traditional. In her survey of elementary school mathematics teachers, Takker (2011) found that teachers understood reforms as change in textbooks and showed familiarity with the vocabulary used in NCF 2005. The classroom observations and interviews with teachers revealed that the vocabulary meant different things to different teachers, and their classroom practice remained unchanged. Teachers often resorted to traditional pedagogies in the lack of time and support provided to engage with the propositions of the reformed curriculum. A few teachers who made attempts to enact the reformed curriculum struggled and faced challenges in handling multiple student responses in classroom, connections between representations, the need for several contexts, etc.

Brodie (2011) argues that research should make visible aspects of reform teaching as teachers try to engage substantively or epistemologically with learners' mathematical ideas. We contribute to the literature on the challenges faced by teachers in making this transition, as we believe it is an important way to unpack aspects of teacher knowledge required for teaching and design subject-specific support required by teachers.

Knowledge of student's mathematical thinking

In conceptualising *mathematical knowledge required for teaching*, Ball and colleagues (Ball & Bass, 2000) identified knowledge that combines knowing about students i.e. anticipating students' thinking and possible confusions, with the knowledge of mathematics. Teacher's knowledge about students' mathematical ways of thinking in practice requires both awareness and skills of interpreting and responding to students while teaching. For a practicing teacher, listening to, noticing, and reflecting on mathematics underlying students' talk can help in developing deeper knowledge of the content (Takker & Subramaniam, *under review*). In their study, Johnson & Larsen (2011) showed how a mathematician teacher's listening was supported and constrained by her mathematical knowledge for teaching. However, possessing the knowledge about students' mathematical ideas does not necessarily translate into teacher actions. Even (2008) problematises the assumed connection between what teachers know about students' thinking and ways in which this knowledge is used in teaching. She argues that the integration of knowledge and practice generates a new object 'knowtice', and teachers need support in developing their knowticing of students' talk. Davis (1997) classifies teacher listening based on its purposes. He points to the difference between listening to evaluate students' responses from listening to make sense of and interpret student utterances. In our study, we found the third purpose of listening, i.e. its transformative potential (Davis calls it 'generative listening') as prominent in supporting teachers' reflection.

In the study reported in this paper, we explored experienced school mathematics teachers' knowledge of students' thinking as it gets manifested in their practice. During classroom observations, we collected evidences of student responses which were significant to a particular topic, and together with the research literature on students' thinking, planned an interactive space for teachers and researchers to engage with these artefacts. We identify these teachers as those *in transition*, as they have spent considerable time teaching mathematics in traditional ways and are now struggling to understand the new curriculum and its implications for their practice.

The study

The research study, of which this paper is a part, aims to explore and enhance teacher's knowledge of students' mathematical thinking as it gets manifested in practice. The objective of this paper is to analyse the knowledge demands posed on a teacher as she becomes more responsive to students' ideas while teaching decimals in Grade 5 classroom.

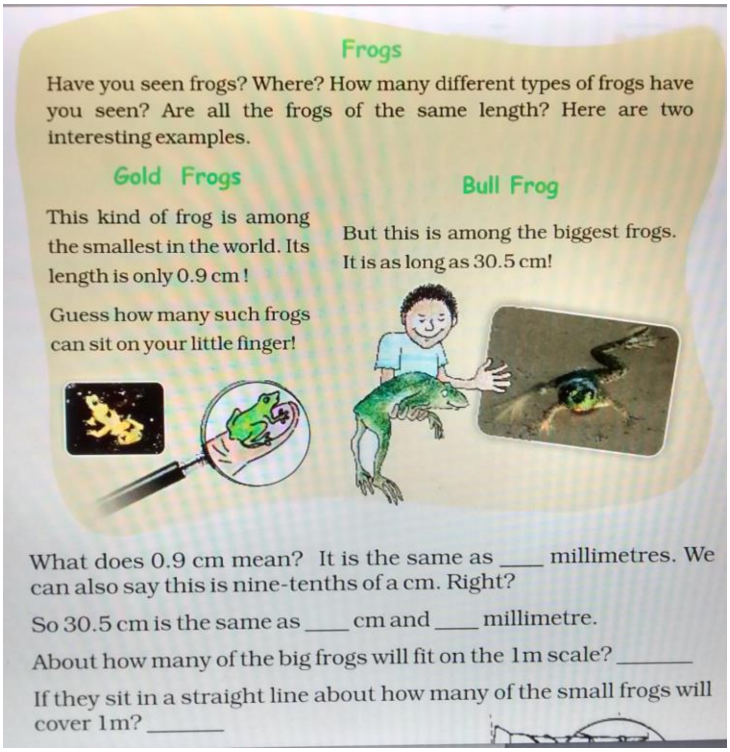
Data and participants

Four elementary school mathematics teachers from a school in Mumbai participated in the two year study. All the teachers had an experience of teaching mathematics for over 15 years. Two of the teachers taught Grades 1 to 5 (approximate age 6-10 years) and the other two teachers had taught Grade 11 & 12, but for the last 8 years, have been teaching Grades 6-10. The data was collected in three overlapping phases. The first phase of the study involved classroom observations of teachers, individual interactions with the researcher, pre and post lesson interactions whenever each teacher's time permitted, and two long interviews with each teacher. In the second phase, all the teachers and researchers met after the school hours to discuss artefacts collected from the first phase, and deliberate more on the teaching of decimal fractions to students. These teacher-researcher meetings (TRMs) were audio and video recorded, and summarised by one participant for all the others. The third phase involved classroom observations of teachers teaching decimal fractions and a topic that follows (division and algebra), pre and post lesson interactions, and other interactions with the teachers. In the beginning of the first phase, data was collected using audio recorder and classroom notes by two researchers. As the teachers became more comfortable, the second half of the first phase and the later phases of the study were audio and video recorded along with researchers' notes. Each teacher was observed teaching the same topic twice i.e. in the first (first phase) and second year (third phase) of the study.

In this paper, we discuss the case of Reema (pseudonym) teacher. Reema has been teaching Grades 1-5 for about 22 years. She has taught with the old and the new curriculum. In the first year, she shared that the new textbooks have more real life problems (or contexts) but less practice exercises. She mentioned that she uses contexts to introduce a topic but often leaves them, as she wants students to become more comfortable with numbers or figures. Reema's case has been selected as she made several attempts to work informally with the researcher to understand the textbook content better and discuss pedagogies, which might be more suitable for her learners in the second year of the study. For the purpose of this paper, transcripts from Reema's classroom teaching are used. The data from the transcript was first parsed through a coding scheme which had descriptors like teacher question-seeking explanation, teacher response- restating, student response- justification, and so on. The coding scheme was generated and refined by studying the transcripts of a teacher's teaching, then validated by other researchers, and used to code data from other teachers' teaching. The codes revealed an increase in student utterances in the second year of data, and the teacher seeking for justification. To understand, the aspects of teacher noticing and their decision making, we decided to go deeper into the episodes which were coded. Each lesson, typically 35 minutes long, was broken down into episodes where a specific mathematical idea or a problem was discussed in the classroom. The duration of the episodes varies considerably depending on the actual class time spent on the problem. The episodes from two years of teaching were paired based on the similarity of the problem or sub-topic taken by the teacher. It was noticed that, the amount of time spent on some of the ideas expanded considerably in the second year, as Reema felt that these ideas needed more discussion in class. We examine a paired episode from Reema's classroom teaching, where a decimal task is being discussed, to show the nature of difference.

Decimal context: Length of the frog

In the revised mathematics textbook of Grade 5, the chapter on decimals *"Tenths and hundredths"* includes several contexts. These include – length measurement (guess and measure length of different objects for instance ant, pencil, candle, ladyfinger, notes or currency, etc.), money and currency exchange, and temperature. The measurement context introduces the unit millimetre, and then poses the length of the frog context (refer Figure 1). I will discuss how the context has been dealt in the classroom in the first and the second year of teaching.


Frogs

Have you seen frogs? Where? How many different types of frogs have you seen? Are all the frogs of the same length? Here are two interesting examples.

Gold Frogs

This kind of frog is among the smallest in the world. Its length is only 0.9 cm!

Guess how many such frogs can sit on your little finger!

Bull Frog

But this is among the biggest frogs. It is as long as 30.5 cm!

What does 0.9 cm mean? It is the same as ____ millimetres. We can also say this is nine-tenths of a cm. Right?

So 30.5 cm is the same as ____ cm and ____ millimetre.

About how many of the big frogs will fit on the 1m scale? _______

If they sit in a straight line about how many of the small frogs will cover 1m? _______

Figure 1: Frog context (Grade 5, NCERT, 2010)

Year 1: Length measurement context

In the first year, Reema introduced decimals using the measurement context. She asked students to look at their 15 centimetre (cm) long scale and introduced the 'guess and measure' length task. Pointing to the markings on the scale, she told students that each number represents a measure – 1cm, 2cm, and so on. Further, between 1 and 2cm, the first line (referring to division) is point 1. She referred to the other parts as "point 5, point 8 and point 9". She asked students to draw an ant of length less than 1cm, and a glass of length 11cm. A few students used the scale to measure objects around them, for instance the length of their finger, eraser, etc. They marked 1cm on these objects and then used this length for the task of guessing, given by the teacher. To draw a length of 5cm, Reema told the students that "5 is less than half of 11", thereby suggesting students to use 11cm length to draw 5cm. She then asked the students to draw a boundary of perimeter 10cm by telling them how to use a thread and scale. The lesson concluded with students working on their drawings, and completing the estimate and actual measures table for all these objects as homework. In the next lesson, Reema introduced the "ths" in *tenths and hundredths* using the money context. Reema decided not to do the length of the frog task as she felt it was very challenging for the students who have just been introduced to decimals.

We notice that Reema took the 'guess and measure' length task suggested by the textbook to introduce decimal numbers. She used a ruler to direct students' attention to the whole number measures and then introduced "point 1, point 5, and so on" as measures between wholes. The students used objects around them as estimates of 1cm and iterated 1cm to guess the lengths - less than 1cm, 11cm, 5cm, and 10cm. Reema did not discuss with individuals or whole class, how they were finding these measures. She completed the task by asking students to measure the actual lengths of the objects drawn by them and evaluated the correctness of their guesses. We observe here that Reema simplified the task of guessing and measuring by introducing the ruler in the beginning. Although, students were not explicitly asked about the lengths on the ruler, the choice indicates that Reema was aware of the students' familiarity with the ruler. The lesson seemed to focus on revision of the whole number lengths, as the measures given did not have a part of a centimetre. Reema decided not to do the length of the frog context, as she struggled to support students in dealing with the problem. She believed that the problem was challenging for students and therefore omitted it. Reema used different contexts (money, currency, temperature) in different lessons and completed most part of what was given in the textbook. However, this discussion was largely driven by Reema introducing the task, asking students to do it or sometimes solving the whole problem on the board and asking students to copy it. While teaching, her instructions were simple and explanations procedural, demanding students to follow and repeat.

In the lessons observed in the first year, we found that Reema did not provide students with an opportunity to solve problems independently, i.e. without her support. Also, she avoided challenging problems like the frog context, which required students to think about the problem and had the potential for discussion in class. The lack of belief in her students' capability of doing mathematics was also evident when she was asked to anticipate her student responses to a particular set of problems, and her students outperformed her anticipation.

As researchers, we made attempts to challenge Reema's (and other teachers') beliefs about their student capabilities and engage them in thinking about the relevance of the measurement context in teaching decimal numbers. A task was planned where Reema was encouraged to anticipate her student responses to a set of problems designed by the researcher but validated by Reema and other participating teachers. After students had solved the problems, the patterns in students' solutions were discussed with individual teachers. We hypothesise that a mismatch between teacher's expectations and students' performance might have helped in challenging Reema's beliefs about the students' capability.

In the teacher-researcher meeting (TRM), we had discussions on the relevance of the measurement context and the choice or linear and area models for representing decimals. In the 13th TRM, teachers mentioned that they used linear model for tenths and area model for hundredths place value. This inconsistency when moving from tenths to hundredths was also found from classroom observations done in Phase 1 of the study. The goal of this meeting was to critically examine disconnect between the models used for tenths and hundredths, and discuss the possibility of using a consistent model. Therefore, teachers were asked to use and reflect on both the models (linear and area) for representing decimal numbers with varying lengths. During the meeting, teachers were shown a one metre long strip made of paper, with centimetre and millimetre markings. They were asked to think about different ways in which this strip could be used for teaching decimal numbers. In the beginning all teachers, including Reema, suggested that the strip could be used for conversion of lengths between centimetre and metre. This was consistent with a focus on tenths using linear model. We directed teachers' attention to the consistency of relation between all the units and across units. The relation between units was expressed using fractions and decimals (for instance, millimetre is 1/10th of a centimetre,

centimetre is 1/100th or $(1/10)^2$ of a metre, and so on). Following this, teachers discussed the possibility of using a linear model for all the place values (i.e. tenths, hundredths, thousandths). Similarly, teachers were asked to examine the potential of the area model (grid of 10×10) for each of these place values. Reema recalled the discussion on the linear model and used it to introduce decimals in her classroom.

Year 2: Measurement and decimals

In the second year, Reema introduced decimals using the 'guess and measure' length task. In the first lesson, she asked students to recall their use of a ruler. A few students mentioned the units – centimetre and millimetre, and Reema took this opportunity to introduce the different divisions in a ruler. She asked students to estimate the length of a few objects that she had carried with herself. These included an envelope, a comb, tin, and marker pen. The choice of the objects seemed deliberate as two of them measured in whole numbers and the other two had measures in centimetres and half millimetres. Reema used these measures to introduce "half or point 5" to students. The whole class discussion on estimates was tabulated on the board and students were invited to measure the actual length and write alongside the estimated measures. In the next lesson, Reema introduced the metre strip as an extension of the ruler and used it to show the relation between metre, centimetre, and millimetre. She first asked students to estimate the length of this strip, and then posed the following questions.

(a) How much is half of the strip?

(b) How many centimetres would be half of the strip?

(c) How much is each part?

(d) Three parts of 10 centimetres mean?

(e) Seven parts?

(f) Eight parts?

(g) What will be the length of two parts on this strip?

(h) In the whole strip, how many two-two parts are there?

(i) And how many five parts are there?

The introduction to the strip using these questions invited students to recall their prior knowledge of half, part-whole meaning of fractions, measures corresponding to fraction parts, measurement of length, and finding relation between units. Further, it made the metre strip familiar to students. Reema directed students' attention to the equidistant parts, and how these parts combine to give a fraction and a whole. While question (d, e, f, g) required students to think about the sub-parts within a part, question (h, i) asked them to look at the whole (1 metre) and identifying how many parts of equal measure (2, 5) can be taken from this whole. While the earlier can be linked with the idea of equivalent fractions, the latter is about equipartitioning where the whole and the unit were given. Reema then introduced the length of the frog context to students. She began by asking them to guess the length of the frog that they have seen. Students guessed different lengths - "5cm, 10cm, 1cm, and 15.5cm". Reema told students that the textbook writers, through their survey, have found that the length of the shortest and longest frogs is 0.9cm and 35cm respectively. She asked students to imagine that the frogs of the same length are sitting on the 1 metre long strip without leaving any gap, i.e. very close to each other. And then she posed the question, how many frogs of length 1cm can sit on the strip. While the students modelled with their hand 1cm, 1cm, and so on; Reema showed these jumps on the strip. She restated and recorded the chorus response given by the students, 100 frogs of 1cm each, on the board. Then, she changed the length of the frog to 2cm and asked the same question. Students immediately responded 50 giving reasons using half. Then, she asked them about 30.5cm long frog. A student, Ashwin, came to the board and located 30.5cm on the strip. When he reached 30.5, Reema mentioned that it is half cm or 5 mm more than 30cm. While thinking of the next frog, Ashwin pointed to 70cm on the strip. Other students responded “71cm, 75cm”. Students gave reasons for their responses like “seventy plus point five plus point five”. When a majority of students seemed convinced with the response, Reema noted this on the board “30.5 + 30.5 = 71 cm?”. Students noticed the response “71cm” on the board and then, with some probing from Reema, corrected themselves to say 60 and 1 is 61. They added the length 30.5 for the third frog and concluded that 91.5 centimetres are covered. Students used the strip to make forward jumps from 91.5 and told Reema that 8.5cm of space would remain. Reema took the opportunity to put the subtraction sentence “100cm - 91.5cm” on the board and verified the answer to be 8.5. She revoiced the discussion on the number of frogs of length 30.5cm and the decimal addition and subtraction. Then, she posed the final question - how many frogs of length 0.9cm can sit on the strip. Initial student guesses were – definitely 100, 100 divided by 9, corrected by another student as 100 divided by point 9, another student said 99 frogs. After spending some time on the problem, four students explained their methods. These were adding 0.9 repeatedly, subtracting 0.9 repeatedly from 100, multiplying 0.9 with 10 repeatedly, and 100 divided by 0.9. Reema recorded these responses on the board. She then asked “how much is 0.9 cm less than 1cm?”. The students stated 1mm and then started adding 0.9s in every 1cm. They kept a track of the space that remains after each frog sits on every centimetre.

1 frog	2 frogs	3 frogs...	10 frogs	100 frogs
-1mm	-2mm	-3mm…	-10mm	-100mm

Together, the class was convinced that the answer was more than 100 frogs. Reema then asked how much more and students started counting the leftover spaces. Now the question was how many frogs can sit in 100mm or 10cm. Soon the class discovered 110 and one more frog as the response.

Reema reflected on this classroom experience in 16th TRM while sharing it with other teachers and researchers. She mentioned that students were interested in the problem and that she wanted them to identify that ten times point 1 makes the space for 1 more frog to fit on the 1 metre strip. In another meeting, she discussed that the use of a metre strip supported the movement from tenths to hundredths. Students showed flexibility in the use of a number line to represent decimals of different lengths unlike selecting a number line to represent tenths only, as in the first year.

Discussion

We notice a change in Reema's teaching from the first to the second year. In the first year, Reema provided procedural explanations to students and expected them to reproduce it for related problems. She selected the content from the textbook depending on what she thought her students were capable of doing. As evident, some of these choices were linked with the breadth of her knowledge about the content. In the second year, Reema posed more challenging mathematical tasks to students. She made attempts to ensure consistency in the choice of models and between contexts and models. Further, she listened to students' methods more carefully, revoiced them for whole-class discussion and proposed more sophisticated explanations. In her teaching, she created variations of a mathematical problem (like the frog context) and supported students in engaging with connections between representations. We attempt to discuss at least two knowledge demands placed on Reema due to the changed pedagogy from the first to the second year.

Reema introduced the metre strip, which was a new tool for students. In order to make the tool approachable for students, she posed some questions related to the relation between different units. Students used this understanding to formulate an explanation for the problem on length of frog. The variations in the questions posed by Reema supported students in formulating this explanation. Thus, Reema's teaching showed the use of linear measurement to invoke students' prior knowledge, introduce new knowledge of decimal fractions, make links between context and linear representation, support flexible movement among measurement units, and offer explanations using the representation. Unpacking the affordance of the context included using it to build connections between students' knowledge and mathematical content, creating challenging task, and supporting students to solve a problem. These aspects seem crucial for supporting teachers' knowledge required for teaching mathematics.

Second knowledge demand has to do with handling multiple student responses. We notice that Reema refrains from passing a judgment as correct or incorrect on the student responses, as was noticed in the first year. In the second year, she was listening to and recording student responses on the board and held whole class discussions to judge the correctness of these responses. We notice the emergence of a few new teaching practices in this year. These include seeking justifications, acknowledging contributions, co-creating explanations, and revoicing. After receiving different correct methods from students on the last problem (frogs of length 0.9cm), Reema offered a more sophisticated solution and together with the class found the answer to the problem. We do not know why Reema did not consolidate different student responses to the problem while offering this explanation. Although, we acknowledge that it is difficult for the teacher to organise different student responses and then connect it with a more sophisticated explanation. We hypothesise that students' independent problem solving supported their contribution in the discussion of the solution proposed and guided by Reema.

We believe that Reema required more support in the second year due to the nature of demands posed on her by the classroom situations. As discussed, these situations included an increased student talk, multiple student responses, affordances of a context and model, and consistency within and across representations. In the second year, Reema demanded more discussions with the researcher prior to the lesson mostly around the content from the textbook and post lessons with a focus on ways of handling individual student responses.

We notice a change in the practice of all the four participating teachers. The analysis from two other case studies, one that focuses on decimals and the other on teaching division, has been reported elsewhere. We are in the process of analysing more such paired episodes from Reema and other teachers' teaching. The attempt of the analysis is to identify topic-specific knowledge demands posed on the teachers as they try to be more responsive to students' mathematical ideas. We believe that unpacking aspects of such knowledge is crucial to support teachers who struggle to make sense of content within the reform contexts.

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NEGOTIATING COMPLEXITY WHILE WRITING SCIENCE TEXTBOOKS: A CASE STUDY OF A DISCOURSE ON FARMING METHODS

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Evidence suggests that school science, as represented in textbooks, is often a simplified version of the official discourse of an idealised science, because it is easier to teach. Since nature does not always fit the simple models, there is a growing number of science educators arguing for teaching complexity, at least on occasions. This study analyses how agriculture, a complex human enterprise replete with several socio-scientific issues, is represented in a recent standard VIII textbook. Macro level critical discourse analysis, multi-stakeholder interviews, and a relevant public debate informed the analysis. Results propose that one reason for the simplification of complexity in textbooks is the tendency to present idealised and romanticised versions of both science and socio-political discourse of the topic at hand.

Introduction

Textbooks exist in a political context (Purves, 1993). They offer ‘clues to the circumstances, hands and forces that created them’ (Issit, 2004). Subjectivities of the policy makers and textbook writers play crucial roles in the process of textbook writing (Darak, 2012). It is also well established that ideologies of the powerful influence curricula (Apple, 2003). Textbooks published by the government through its agencies also reflect the predominant ideologies that the state wants its citizens to abide by, aligning with the prevailing politico-socio-economic conditions.

School curricula, especially in India, continue to be mostly centred on textbooks (Kumar, 1988 & Advani, 2009). In this scenario, science textbooks have a seminal role to play in the science educators' call for the creation of a scientifically literate citizenry (DeBoer, 2000; Ramnarain & Chanetsa, 2016) equipped with the knowledge to handle complex environmental challenges (Colucci-Gray et al, 2012; Sharma & Buxton, 2015) and uncertainties of the anthropocene (Gilbert, 2016).

Science is a complex social institution. Public understanding of science and also the school science discourse are usually an idealised version of what science 'ought to be' (Allchin, 2013, pp 77-91). Though textbooks are written after careful deliberations and filtrations at various stages, they usually end up representing some fragments of only the official discourse of science, and the process of selecting the textbook discourse is greatly influenced by the immediate socio-political contexts (Rudolph, 2003).

Negotiating socio-scientific issues

Though there are some counter examples, textbook discourses are mostly seen in agreement with the norms and values of the corresponding society. What happens in the process of writing textbooks that gives it a particular orientation to the public understanding of science? Especially, it is not easy to decide which facts to select from various bodies of knowledge related to a particular socio-scientific issue to be included in textbooks, which have similarities, differences and conflicts among the philosophical, epistemological and ontological foundations. How exactly do textbook writers negotiate through this obviously difficult task? Case studies on this problem are rare, especially from India.

A case study

To understand how textbook writers negotiate complexity while writing science textbooks, the case study of a textbook topic having complexity was conducted. A complex human enterprise like agriculture, which carries immense socio-cultural, economical, historical, and political significance, was found to be suitable for this. Accordingly, a chapter on agriculture, titled 'Let's regain our fields' from standard VIII Basic Science textbook used in Kerala, a southern Indian state, published by SCERT[1] was selected. Tools used in macro level critical discourse analysis (Fairclough, 2004) were employed to aid the case study. Multi-stakeholder viewpoints were gathered using interviews of a textbook writer, a permaculture enthusiast, and a conventional farmer. Arguments from a public debate[2] between an organic farming activist and a thought leader scientist in Kerala were also used to inform the study.

A literature survey of the prevailing socio-political environment in Kerala guided the investigation to understand the 'social body of agriculture' (Carolan, 2006). The question 'What methods of farming are practised?' led the analysis of interview and debate data. Methods of farming were taken as the basis for the discourse analysis, because they represent an operational summation of the social body of agriculture, each method being more or less the representation of a distinct philosophy of human-nature relationship. Following questions were used as pointers to do the coding of the textbook content:

- To which method of farming does this section in the textbook adhere to?
- How does this section relate to other sections?

Methods of farming

Farmers are a heterogeneous group. From the subsistence agriculture of the pre-colonial period to Green Revolution and to the recent organic farming movements, Indian farmers negotiated their roles and identities like their counterparts worldwide. In many parts of India, there still exist farmer communities practising the subsistence agriculture of pre-colonial era. Indian farmers widely vary in terms of their knowledge traditions, economic status, nature of farming, techniques and methods used,

1 State Council of Education Research and Training. Around 85 percentage of the student population in Kerala follow the textbooks published by SCERT.

2 Available on https://www.youtube.com/watch?v=_x_skUD-pjs

and their world views. Those who practice subsistence agriculture and urban dwellers who do rooftop gardening are included under the same group 'farmers.' Methods of farming also show a corresponding heterogeneity. Though it is just one aspect of the complex dimensions of agriculture, whether organic or conventional method is employed is an important feature to consider as far as agriculture is concerned. A tabulated summary of the different methods and their salient features, understood through literature survey and interviews, is given below (Table 1).

Methods of farming	**Salient features**
Conventional industrial	Large scale, technology intensive, high input mono-culture of crops for the market. Increasing profit is their major motive. Chemical pesticides, weedicides and fertilisers are inevitable. Big corporations own the farmlands and they hire scientists for research and development of improved agricultural technologies for them.
Conventional	Mono-culture of crops for the market. Small-scale, when compared to the industrial mono-culture. Requires high external input in the form of chemical pesticides, fertilisers, high yielding seeds, etc. High dependence on market forces and government policies. Some farmers also use organic manure and pesticides along with the artificially synthesised ones.
Traditional	Low-input, small-scale, labour-intensive method followed by traditional farmers who continue to do what their ancestors taught them. Characterised by a general resistance to anything modern.
Organic industrial	Conventional industrial agriculture minus artificially synthesised pesticides, weedicides, and fertilisers. Large-scale mono-culture of crops for the market. It is technology intensive and requires high external input.
Organic-popular	Many farmers newly entering into farming, inspired by the organic farming movements, follow this method. Traditional and conventional farmers sometimes switch to this method for the same reason. They cultivate for both domestic use as well as for markets. They criticise the conventional farming method at every opportunity. They are ready to follow modern methods like aquaponics, poly house farming, drip irrigation etc.
Organic-vegetable gardening	Influenced by the rhetoric of organic farming movements, a fear of health-hazards from consuming pesticide residues from the market-sourced vegetables motivates many to grow vegetables for domestic use. Hobby farmers, backyard farmers, kitchen gardeners, and students mostly do this. Marketing is not intended.
Agro-ecological (Natural farming methods like zero-budget, permaculture)	Informed by the science of Ecology, farmers who follow these methods consider themselves as stewards of the environment, who are usually interested in philosophising their practices. Productivity, stability, sustainability, equitability are some of the important principles held by them. Simulating and utilising the natural patterns in the ecosystem to grow plants, they consider themselves as just helpers of the nature.

Table 1: Different methods of farming

Recently, Kerala has been witnessing heated debates between the proponents of different farming methods, especially between the practitioners of 'organic popular' and proponents of 'conventional' methods. Proponents of conventional farming accuse organic farming activists ('Mafia' in their words) of fear mongering about pesticides and misguiding the political leadership. They argue that the conventional method has proved successful in feeding the population. Even now, we are heavily dependent on conventional methods. If properly used as recommended, pesticides do not cause diseases. Even sunlight and tobacco decoction have carcinogenic properties. A strong correlation between cancer and pesticides has not yet been proven. Hybrid seeds are inevitable now. Discrediting all these modern technological advancements will push us into becoming a starving population. Even a proper scientific definition of 'organic farming' is not available, they argue. They also add that organic farming cannot feed the masses, and it is only for those hobby farmers who do farming for recreation. However, the Kerala government continues to promote organic farming through its machineries, standing by their declaration to convert the state to fully organic by 2020.

The organic farming methods clubbed together under agro-ecological farming have many similarities and disagreements with each other. For example, a famous permaculture enthusiast in Kerala, K.V. Dayal, who has also authored books on permaculture, does not approve of some of the practices in Subhash Palekar's Zero-budget farming[3], like depending on only one indigenous cow, not diversifying crops at a time, etc. He also believes in going a step ahead from Fukuoka's 'Do-nothing farming', in that once we understand how ecosystem functions, we can greatly enhance that process using ecology principles. Though he identifies himself as the proponent and practitioner of permaculture, his philosophy seemed to border on Bio-dynamic farming[4], which includes spiritual and mystical dimensions. He leads a permaculture practitioner's group of 300 members (and growing), many of them having successful permaculture farm fields. Permaculture practitioners like K. V. Dayal has the conviction that their method is sufficient to feed the population.

The conventional farmer shared the practical difficulties to switch to organic farming. Organic farming is labour-intensive, which is a crucial factor in Kerala, where labour shortage and high rate of wages simultaneously exist. It is not practical to source organic manures in the required quantity. It is a labour-intensive and expensive process to uproot weeds one by one, instead of just spraying a weedicide. When farmers have invested a huge sum on the crop, they would not want to take a chance and try tobacco decoction to address the immediate threat of a blight disease. They will go for chemical pesticides, an already proven remedy.

The practical details of the tensions between various farming methods are murkier if one considers the political dimensions and philosophical differences. Statements like “What if other organisms are dying because of conventional farming? We (humans) are here to survive. Extinction of organisms is not a new phenomenon. Those that can survive will remain. That's how it is” could be heard in this arena. Instead of demarcating farming methods into strict categories, it is more useful to see it in a continuum, because most often, a mixture of these methods could be seen in the same field. Conventional industrial agriculture and agro-ecological farming could be placed at the two ends of this

3 Zero budget farming focuses on soil health. Mulching, mixed cropping, and applying Jeevamritha (a preparation containing cow dung and urine of a traditional Indian cow) are some basic agricultural activities of this method. No inputs are supposed to be brought from outside, hence the name.

4 An alternative farming method which rely upon esoteric knowledge and mystical beliefs mainly drawn from the ideas of Rudolf Steiner.

continuum. The philosophical foundations of these methods show a change from reductionist (Colucci-Gray et. al, 2013) to holistic (Capra, 1996) understanding of science from one end of the continuum to the other (Figure 1).

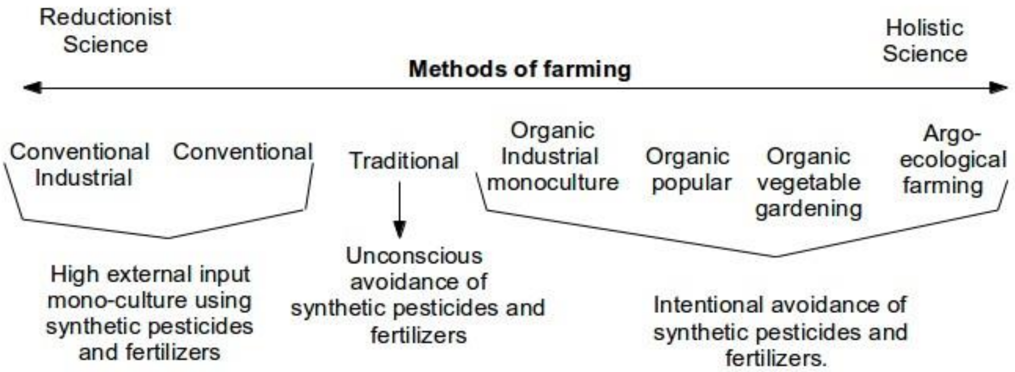

Figure 1: Methods of farming based on the use of synthetic inorganic pesticides and fertilisers

Analysis of a chapter on agriculture

The chapter on agriculture in the Std VIII SCERT (Kerala) Science textbook titled 'Let's regain our fields' had 13 instances of favouring organic farming (Table 2). Contrastingly, acknowledgement of the role of technology intensive modern scientific methods in ensuring food security was the only instance where conventional method was positively shown. This is also in agreement with the statement by the textbook writer who led the writing of this chapter, that they (writers) were clear that this chapter should be supportive of the organic farming movements.

Positive/ Supportive mentions of organic method	**Negative mentions/ criticisms of conventional method**
1. Microbial fertilisers for better yield 2. Need for technological research on new methods of mechanical pest control, to avoid use of chemical pesticides 3. Integrated Pest Management is an ecofriendly method. 4. Sustainable agriculture is relevant, it helps in reducing market dependency and maintenance of biodiversity 5. Fertilisers, biogas, and fodder from organic waste 6. LEISA (Low External Input Sustainable	1. Environmental destruction and health issues 2. Chemical fertilisers or chemical pesticides should not be used while using microbial fertilisers (Conflict) 3. Creating awareness among farmers on the consequences of unscientific application of chemical fertilisers 4. Chemical pesticides are harmful to our health and nature 5. Though the excessive use of fertilisers and chemical pesticides provide profit for a short period, gradually the land may

Agriculture) to NEISA (No External Input Sustainable Agriculture) is a desirable change. 7. Online groups of farmers addressing the demand for organic products, eliminating middlemen, thus increasing profit.	become barren 6. Changing perspective- It is more sustainable to change from HEIA (High External Input Agriculture) to LEISA

Table 2: Instances of favouring organic farming from Std. VIII Science textbook (SCERT, edition 2015)

The chapter acknowledges the high yield from hybrid seeds. However, it is immediately followed by a call to preserve the indigenous varieties of crops used in the traditional farming method for their adaptability to local climate, nutrition and taste value, and resistance to diseases. At another instance, it states 'there was no need to use chemical fertilisers or chemical pesticides, since it was an indigenous variety of rice.” The chapter also gives an assignment for students to collect information on the indigenous varieties of different crops.

One of the stated purposes of the chapter is that the learner can 'identify the greatness of agriculture and learn to respect farmers.' To serve this, similarities between the activities of a scientist and a farmer are listed down. 'A real farmer is a scientist because s/he applies scientific method' is the immediate conclusion reached. This invokes many questions. Why tag farmers as scientists? When does an everyday activity become science or non-science? Social recognition that scientists get could be the reason that prompted textbook writers to give a scientist tag to farmers. If so, discourses like these eventually serve the opposite purpose, because in the real world, both scientists and farmers, like any other groups of people, have their own roles, scope of work, and methods, which have similarities and differences. This tendency to romanticise science, by shoehorning it into 'the conventionalised scientific method' (Allchin, 2013, p 68) conveys a wrong notion of reality. “Students need to see that nature does not always fit the simple models in the textbook” (Allchin, 2013, p 132). The problems in agriculture and proposed solutions as discussed in the chapter (summarised in Table 3) also reinforce the idea that “school science prepares students only for simple problems” (Allchin, 2013, p 130).

Problems	**Solutions**
Exploitation by middlemen, and fall in price	Agricultural societies and supporting organizations. Organisations that connect farmers to customers. Online groups of farmers marketing organic products.
Climate change & crop loss	Adopting modern practices like poly house farming, precision farming, hydroponics and aeroponics.
Cost of production	Methods like Integrated Pest Management (IPM) reduces pesticide cost. Supporting organisations that provide storage and marketing facilities help in increasing profit.
Lack of space	Terrace cultivation, Grow bag cultivation, Vertical farming.
Environmental & health issues	Scientific application of fertilisers, IPM, Organic waste management.

Table 3: Problems in agriculture and its solutions as discussed in the chapter

Learning to implement and propagate agricultural practices that are harmless to the environment and health is a stated learning outcome of the chapter. One can see that the discourse serves this purpose. Though cursorily, the rest of the discourse in the chapter is in consonance with this purpose. One can see that textbook writers could negotiate their way into creating a discourse promoting a romanticised organic farming method, while acknowledging the achievements and desirable features of conventional and traditional methods.

Discussion

As told by the textbook writer, there was a determination that the discourse should be supportive of the organic farming movements before beginning to write this chapter. Even the state government had declared their support for such movements. Some authors describe the increasing focus towards organic farming in Kerala as a silent revolution (Thottathil, 2014). Though organic farming movements are gaining momentum worldwide, mass participation of people from various fields- the government, political parties, civil society movements and organisations, conventional farmers, agricultural research stations, scientists, educational institutions, press and entertainment media, religious bodies, social networking sites, environmental activists, intellectuals, and writers- is a unique feature of Kerala's organic farming movements. This social environment most likely shaped the textbook writers' determination to favour one method of farming over the other.

However, if probed deeper, one can see that both the proponents of conventional and agro-ecological farming methods- those at the two ends of the continuum- may have disagreements about this agricultural discourse if asked what they want children to learn about agriculture. Proponents of conventional method have obvious reasons to be unsatisfied about this discourse.

They may say this is a path towards Carter's vulture[5]. Shri. Dayal, the permaculturist, is of the opinion that agricultural education should be focusing on our relationship to the soil, and how our development (physical, mental, social) is closely coupled with it. It is wrong to focus just on learning how to harvest good yield.

The textbook discourse around agriculture does not belong to conventional, traditional, or organic method fully. It advocates a middle path, and do not take a firm position or philosophy, but an attempt is there to favour/ promote the popular romanticised version of the organic farming. The problems in agriculture it presents may not get solved with the solutions it proposes in practical situations, especially when the problems originate due to systemic factors like government policies or due to absence of scientific consensus. But the discourse has the potential to generate opportunities to delve into deeper learning goals, like understanding the nature of science (NOS), given the teachers are equipped enough with the skills to do so. However, this does not happen most likely, because of the time constraints, lack of teacher autonomy, and inadequate training.

People in Kerala heavily depend on the food produced in other states using conventional methods. Majority of the agricultural fields in Kerala also rely on chemical fertilisers and pesticides. Other than

5 Title of a book by Dr. K M Sreekumar and Ravichandran C. (The Vulture of Carter) published by DC Books, Kottayam, in 2017. It explains the importance of conventional agriculture. Without it, we will be inching towards Cartor's vulture starvingly, as in the famous photograph by Kevin Carter, waiting to be eaten.

anecdotes and doubtful examples, it is not seen in large scale how organic farming methods can solve problems in agricultural sector. Still, we have seen that the agricultural discourse in the textbook explicitly promoting organic farming method. That too, a particular, romanticised version of the organic farming which is mainly based on the fear of consuming cancer causing pesticide residue from the vegetables imported from other states. Safety of the food is the foremost reason why the Kerala government is also promoting organic farming. However, because of this rather reductionist focus, agro-ecological philosophies about our embeddedness in nature and the inevitability of our harmonious coexistence with it take a back seat.

One of the macro level problems in agriculture cursorily mentioned is climate change, for which poly house farming and hydroponics are proposed as solutions. The solution to a highly complex problem such as climate change thus gets reduced to an individualistic level, to taking refuge inside some pieces of plastic sheets. It could be because of the tendency towards the middle path, adhering to the popular understanding of 'how it should be,' that oversimplification seeps in while negotiating complexity. Even, science itself tends to get idealised and reconstructed, and shoehorned into prescribed norms, apparently for the ease of teaching. It doesn't have to be like this, since, it has been reported that "students typically learn to appreciate the complexities of the nature of science and the challenges of resolving problems" (Allchin, 2013, p 225).

Implications

Despite the shortcomings discussed above, this chapter still serves many of its purposes. Towards the end of the chapter, it reads "Many issues are yet to be discussed," and leave it for the students to "collect more information from farmers, research institutions and media." After all, an in-depth academic engagement that takes into consideration all known aspects and viewpoints of a complex system may not be required or possible to achieve in a school science textbook.

However, certain questions remain. Is it important for school textbooks to take a stand, or have a philosophy? Or is it just a platform for listing out various standpoints regarding an issue and are students supposed to build/ choose their own standpoints? If the textbook writers decide that its discourse should favour a particular ideology/ method/ viewpoint, would it always be the middle path, which reproduces the corresponding social world?

What is it that students lose out on, at the end?- It could be the 'Whole Science' (Allchin, 2013). They may get some random values like not to use chemical pesticides or fertilisers indiscriminately. They may learn how to prepare organic fertilisers, and also the importance of IPM, integrated farming, poly house farming etc. But they lose out on some significant debates in science studies (reductionist vs. holistic), which may prepare them for the challenges of increasingly complex world and uncertain futures, which science educators are increasingly giving attention to, lately. Also, the aspect of the NOS that this discourse can bring in, which could have led to a great opportunity to teach NOS, is missed.

Acknowledgements

I thank Prof. G. Nagarjuna and Prof. Sanjay Chandrasekharan for their suggestions.

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EVALUATION OF STUDENTS' COGNITIVE SKILLS USING OBJECTIVE TYPE QUESTIONS

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Evaluation of students' understanding of the concepts can be done using objective types of questions. Such questions need to be designed such that they test students' higher order cognitive skills likes application, analysis and synthesis rather than mere recall of information. Three questions are presented here which have both the components, namely, the knowledge recall skills and higher order cognitive skills. Students' responses to these questions are discussed.

Introduction

Evaluation systems are usually meant to assess students' understanding of concepts covered in the curriculum. Such evaluations could be performed using either subjective or an objective type of assessments. The rapid growth in knowledge in the discipline of biology has led to questions about the importance of facts and a shift towards an emphasis on equipping students with the skills and knowledge to find, analyze, synthesize and apply information to new situations and challenging problems. In the current education environment of increasing class sizes and decreasing teacher to pupil ratio, objective/multiple choice exams remain a cost-effective assessment method. However, design of such questions is an important aspect of such assessments. If the questions merely test the recall of facts, it is likely to encourage adoption of superficial approaches to learning, such as memorizing facts and processes, rather than critical engagement with the content. It is therefore increasingly important to design objective tests that effectively assess higher cognitive skills such as critical thinking along with the subject knowledge.

An attempt to analyse responses of students to questions that require information recall, reasoning abilities and interpretative skills has been done in this paper. Three such objective types of questions along with students' responses are presented here. The study subjects were a group of 25 high school students who were all high achievers in their respective schools in the routinely conducted tests. The observations from this study can help to understand the general scenario with respect to student learning competencies.

The questions included in this study were part of a national examination and have gone through peer-reviewing process before presenting to the students thereby eliminating the possibility of alternative or incorrect interpretation of the questions.

Each question has more than one component that tests students' varied competencies. A question is categorized as 'knowledge-recall' question if the information required to answer the question is directly available in the standard books. Thus, such questions can be correctly answered by simple memory recall.

On the other hand, a question has been classified as requiring 'comprehensive and interpretative skills' if minimal factual recall is required and the question can be correctly answered by processing and analyzing the data provided.

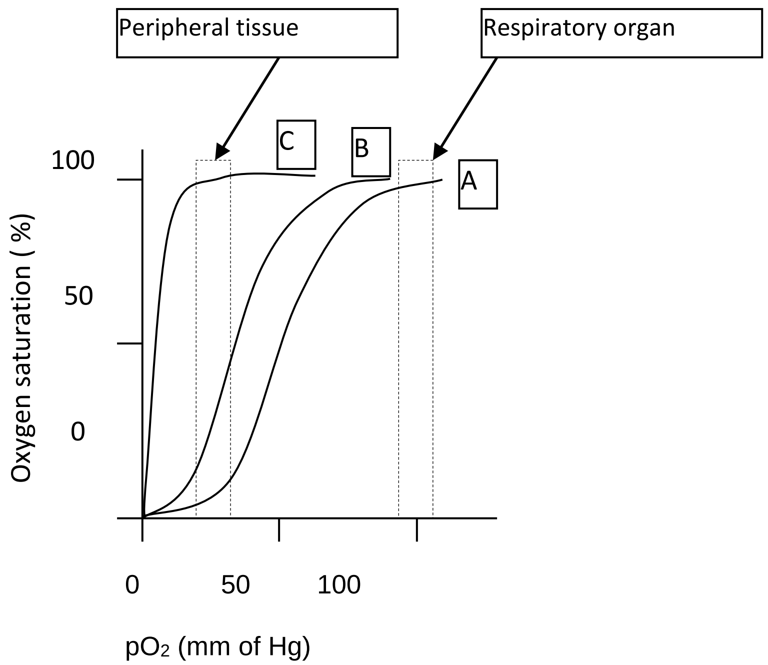
Question testing 'application and synthesis skills' require a student to not only process the given data but also to deduce by putting together their conceptual understanding in the given situation.

At the end of each question, the competencies tested are given in parentheses.

Questions that test knowledge-recall are classified as those testing the Lower Order Cognition (LOC) skills of students while questions involving comprehensive and interpretative skills as well as application and synthesis skills are classified as questions testing Higher Order Cognition (HOC) skills.

Question 1: Area: Animal Physiology

Typical oxygen saturation curves of three protein molecules A, B and C are shown.



Indicate whether each of the following statements is true or false:

1. Curves indicate that protein A is a more efficient storage protein for O_2 as compared to B and C. ***(Comprehension and Interpretative skill)***

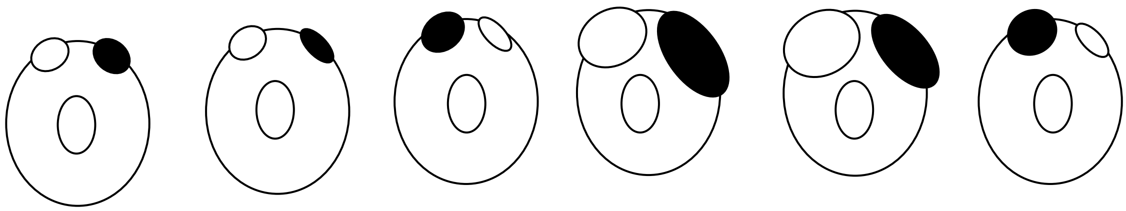
2. In humans, the adult and the fetal hemoglobin molecules would show curves similar to A and B respectively. ***(Knowledge- recall skill)***

Question 2: Area: Ethology

A well known example of fixed action pattern (FAP) is that of Herring gulls that lay eggs in shallow nests on the ground. If an egg rolls out of the nest, it is retrieved by the parent. This behavior is exhibited even if the egg is replaced with a dummy egg. In a series of experiments called 'titration technique', ethologists Barends and Kruijt investigated whether the position of an egg in the nest and /or size had any effect on its retrieval.

The diagram below shows the titration method in which a series of experiments were carried out using varying sizes of eggs for determining whether there is any side preference for retrieval of eggs by the parent bird (Set I). The big circle represents the nest with one real egg in the centre of the nest and two dummy eggs on the rim. ***'r'*** *is the ratio of the sizes of the dummies on the nest rim. The dummy chosen by the parent bird in each trial is indicated by black-filled shape.*

Set I



r = 1 r = 1.3 r = 1.5 r = 1.3 r = 1.3

Based on the results of the experiments in set I determine whether each of the statement is true or false.

A. *There is a side preference for the left whenever the left egg is of a bigger size.* ***(Analysis and Interpretative skill)***

B. *The choice of position is random and does not depend on the size.* ***(Analysis and Interpretative skill)***

C. *There is a side preference for the right. This preference is maintained even when there is a marginal difference in sizes.* ***(Analysis and Interpretative skill)***

Question 3: Area: Biosystematics

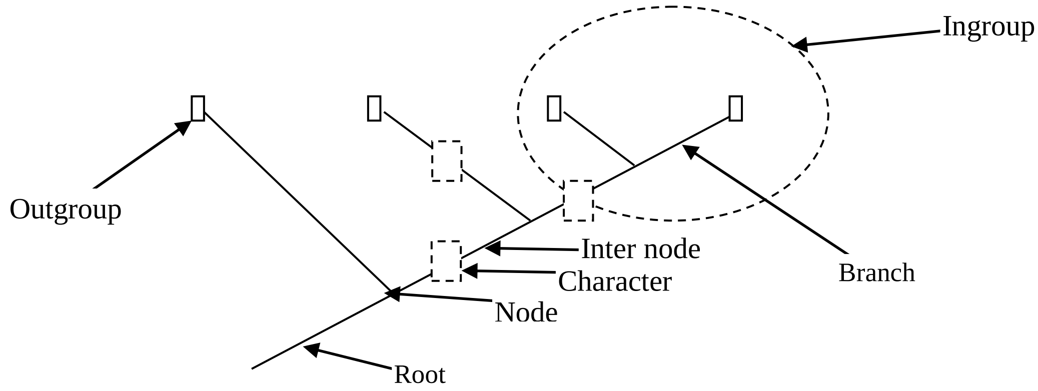
(I) **(*Knowledge recall skill)***

Animals can be grouped or classified based on the presence and absence of external as well as internal key characters. A few animal groups are listed in the given table. Fill in the table with 1 for presence and 0 for absence against the specific characters for each group of animals.

Sr. No.	Class/group	Bony skeleton	Four chambered heart	Four Appendages	Mammary glands	Jaws	Post orbital fenestrae
1	Outgroup	0	0	0	0	0	0
2	Sharks						0
3	Ray-finned fishes						0
4	Amphibia						0
5	Primates						0
6	Rodents						0
7	Crocodiles						1
8	Aves						1

(II) ***(Application, analysis and synthesis skill)***

Cladogram is a tree-shaped diagram used to illustrate evolutionary relationships between groups of animals by analyzing certain characters, or physical features. A representation of a typical cladogram is shown below. Construct the most parsimonious cladogram for the eight groups of animals given in the table and indicate the characters at the appropriate nodes / internodes /branches of the cladogram.



Analysis of the responses

The student responses are represented in the bar graphs 1 – 4. The blue bars in the graphs indicate the LOC skills such as knowledge- recall while red bars indicate comprehension and other HOC skills.

Question 1 deals with the physiology aspect of respiration. The three curves (A – C) in the question represent differences in the hemoglobin saturation property of three molecules when exposed to a gradient of partial pressure of oxygen. As seen from Graph 1, all the high achievers were successful in arriving at the correct answer to component 2 of the question which was a knowledge-recall question (comparative graph of fetal and maternal hemoglobin is often provided in the biology books) while component 1 which required comprehension skills such as understanding information and predicting consequences could be done by only 76 % of the high achieving students.

Question 2 is based on a real life experiment performed by scientists. The experimental design used by the scientists is presented in the form of data before the students. In this problem, observing and recognizing patterns is essential to solve the problem and no prior knowledge would be essential. An entirely new situation is presented in the question for analysis. As seen in graph 2, the success rate of the students is close to 50 %. Merely 16 % of all the students could get all the three answers correct.

Question 3 is based on the classification of animal kingdom. Majority of the textbooks deal with this area in a rather classical way, more by describing the animals and /or their internal structures. It is less frequently taught with the perspective of structure-function analysis or from the perspective of evolution. Graph 3 shows the response of students to this question. Students have been successful in the knowledge recall up to a level of 96 %. However, when it came to analyzing data and synthesizing new pattern, correct response obtained was 16 % (Graph 4).

Discussion & Conclusion

Three most common approaches that are observed in students' learning process are surface approach, deep approach and strategic approach (1). Students who adopt surface approach, rely more on memorizing the information and interact passively with the material. In contrast, deep approach can lead to concept understanding, ability to compare and contrast the data and analyze the situation. The third approach can be a mixture of both the above approaches.

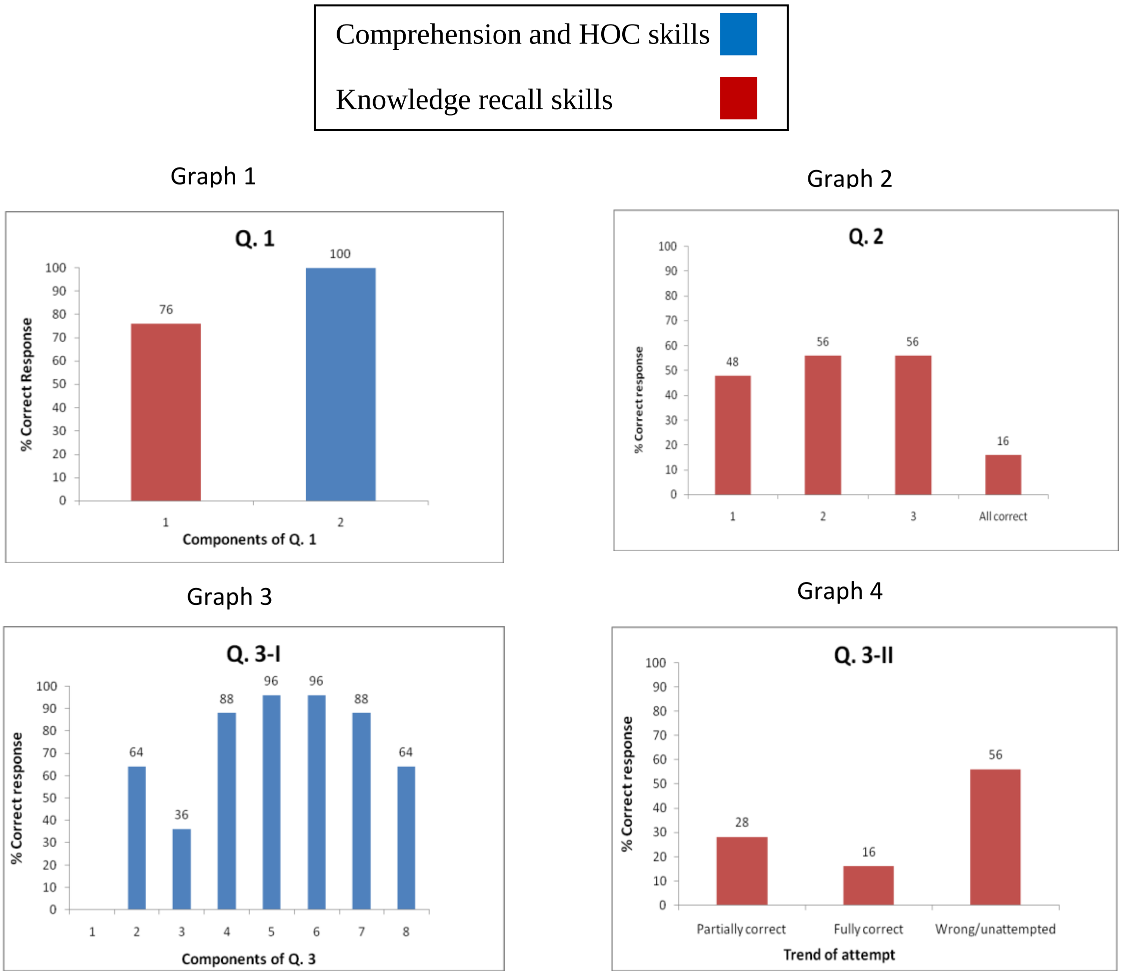
Bloom's taxonomy has identified six levels of cognitive skills which represent simple to complex skills and concrete to abstract thinking in students (2). It classifies the skills as 'Lower Order Cognitive (LOC)' and 'Higher Order Cognitive (HOC)' skills. Within LOC skills, observation and recall of information is at the base while comprehension of text, comparing and contrasting the facts and predicting the outcomes is considered at the next level of LOC skill.

HOC skills encompass along with skills mentioned in LOC, higher cognitive aspects such as problem solving in new situation (Application), recognizing patterns and organizing components (Analysis), creating new module using old ideas and generalizing from the facts (Synthesis).

As it is clear from the data presented in the graphs, even though the students are high achievers in the subject, they perform well mainly in LOC skills and severely fall behind when HOC skills [Question 1. (1), Question 2 (1, 2, 3), Question3 –II] are tested. Since high achievers have demonstrated lack of HOC skills, it could be deduced that the situation at the general classroom level could be more worrisome.

The findings also reflect students' approach to learning the subject. The important question is why the high achievers are adopting to surface approach to learning. It is probably due to the fact that most of the assessments conducted as entrance tests or regular school/college exams mainly emphasise on recall of information/knowledge without inclusion of any challenging situations to students. As a result, the teaching-learning process also caters to these needs. If the objective of science education is to inculcate scientific aptitude in students, then it is necessary to design assessments for testing analytical skills of students. This, in turn, could lead to a change in the teaching-learning approach.

There could be several ways that could lead to active learning as suggested by the deep learning approach such as exposing students to puzzling situations where they have to read data tables, analyse graphs and data. In biology, learning structures is of great importance. This, if done in correlation to respective functions and taught in a comparative manner, it can bring about greater understanding of structures and processes. Furthermore, if biology is taught with the perspective of evolution, it could lead to an even clearer understanding of the subject. Adopting such approaches in teaching can definitely improve the learning and HOC skills of students. However, these approaches would be put to practice only if the assessments are designed in a manner that tests these skills.



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WHAT FARADAY COULDN'T SEE IN HIS GOLD SOLS. USING CLASSIC RESEARCH ARTICLES TO IMPLEMENT PROBLEM-BASED LEARNING IN NANOSCIENCE

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Problem-based learning (PBL) is a student-centered pedagogical approach that is organised around collaborative problem-solving, providing a context for learning. Classic research articles form a rich source of 'problems' to implement PBL. This paper describes a plan to set up a PBL in nanoscience class. Michael Faraday's seminal 1857 Bakerian Lecture is taken up for this purpose, for instruction on synthesis and optical properties of gold nanoparticles. Juxtaposed with other important articles of the time, it is envisaged that students would gain an understanding of the genesis of the field of nanoscience, and an appreciation of historical scientific experiments as pedagogical tools.

Introduction

With research in cognitive science reaching new frontiers, there is now increasing knowledge on how people learn (National Research Council, 2001). Accordingly, efforts are being made to adopt these findings in classrooms with varying degrees of success. Instructional methods, in particular, are being modified in a wide range of academic settings and disciplines, as it is now known that learning gained by students nearly triples when the focus shifts to the students and to interactive learning (Fagen et al, 2002). One such educational approach with a constructivist view to teaching-learning that shifts the focus from the teacher to the student is problem-based learning.

What is problem-based learning?

Problem-based learning (PBL) is a pedagogical approach originally developed in medical schools over half a century ago (Barrows & Tamblyn, 1980), later applied across disciplines at the secondary and tertiary levels of education. As an instructional approach, PBL promotes enquiry in science learning.

PBL came into existence in keeping with the need to change how we teach in accordance with the knowledge of how we learn. Underlying this pedagogy is the tenet of social constructivism, which connotes that knowledge is constructed in the minds of the learner by the learner (Bodner et al, 2001; Bodner, 1986). The implication here is that the building up of knowledge is aided by cooperative social interactions. The teaching by telling method as a means to transfer knowledge from the teacher to the student is not generally effective for many if not most students. With increase in cognitive load on students, it becomes imperative that they be engaged in the learning such that they actively build for themselves an understanding of concepts presented in the class, thereby engaging their higher order thinking skills. The PBL method is particularly suited to creating such learning environments.

In a typical PBL implementation, a problem is presented to students, soliciting their views on how to solve it. The scientific concepts underlying the solution to the problem are not presented to the students in the beginning. Once the discussion ensues, the underlying scientific principles are explained to them as needed. The hallmark of this type of active learning is therefore that the problem comes first and the concepts come later. Several implementations of PBL have been reported across disciplines. In chemistry too, successful implementations have been reported (Ram, 1999; Senocack, 2007; Belt et al, 2002; Summerfeld et al, 2003; Belt & Overton, 2007; Grant *et al,* 2004; Heaton et al, 2006). As with developments in all teaching methods, PBL has now been adapted into a dynamic-PBL, where the problem scenario is not static (Overton & Randles, 2015).

PBL - the relevance

Vigyan Prasar, a constituent body of the Department of Science and Technology, Government of India, conducted a survey in 2011—The International Year of Chemistry—and reported that a main reason why chemistry wasn't popular among students was because they could not relate to chemistry as the way it was being taught in schools. There was thus a big gap between chemistry as it transpired in the world we live in, and chemistry as it was taught in the classrooms. Understandably, chemistry found few takers among the students (also see RSC, 2005). The logical way to improvise this problem is therefore to present chemistry to students, forming conduits which link textbook chemistry to chemistry in the real world. PBL as a teaching pedagogy strives to reach this goal by presenting the concept to be taught in the form of a problem situation that the students need to solve. In a PBL implementation, students typically work in small groups aided by an instructor. They learn on a need-to-know basis by a group-directed exploration, thereby paving the way to becoming self-directed learners (Loyens et al, 2008). This integrates the students' societal knowledge with the chemical principles, so that they get a first-hand experience of applying chemistry in the attempt to solving a problem.

Where do problems in PBL come from?

PBL entails the introduction of the content in the context of real-world problems. The classic research articles provide a rich source of problems for PBL in the sciences (White, 1993). By using these articles in the classroom, students also gain an appreciation of how that particular topic originated and developed over the years. This paper describes the use of Michael Faraday's 1857 Bakerian Lecture to set up a PBL in *nanoscience* with specific focus on the synthesis and optical properties of gold nanoparticles (Faraday, 1857). The PBL pedagogy outlined here has not been implemented by the author; the paper however is intended to serve as a useful initial guideline to educators in *nanoscience*, with the invitation to critique to refine it further. The student population of interest here is final year M.Sc. chemistry students. The author conceived this PBL idea while teaching at a previous institute, where she had been offering nanoscience as an elective course to postgraduate students in chemistry. Being an elective course, it had a maximum strength of about 15. This small class strength coupled with the experience of offering the course for three years, spurred the author on the PBL path.

Faraday's article in the historical context

Faraday's research in the 1840s and 1850s concerned the interaction of light with matter. One of his prime concerns was whether metals were continuous material substances or particulate in nature. Faraday was not favorably disposed towards the view of matter as hard material particles (Daltonian atom), and thus sought evidence for gold being continuous in his extensive research on gold foils in

1856. Faraday particularly made use of gold films thinner than a commercial gold leaf in his work.

On February 5, 1857, Michael Faraday delivered the Bakerian Lecture at the Royal Society in London. Titled ‘Experimental Relations of Gold (and other Metals) to Light’, the lecture clearly demonstrated his fascination with the ruby color of colloidal gold. The lecture described his wide ranging experiments with metal hydrosols, thin metal films, and metal island films done mainly with gold. The main thrust however was on the ruby color produced by fine particles of gold which are ‘very minute in their dimensions’.

Faraday’s observation of ruby-gold and the recognition of its special properties is widely recognized as the birth of modern nanotechnology (Thompson, 2007). Although Faraday did not use the word ‘colloid’ (it was coined by T H Graham in 1861), we now know his sols to be colloidal particles of gold.

Colloidal gold has been used as a colorant since as early as 5 BC in making ruby glass and in imparting a reddish tinge to ceramics. Alchemists and Indian ayurvedic practitioners are also known to have concocted colloidal gold dispersions (Ray, 1903). Faraday however gets the credit for the earliest definitive study on gold sols. He made use of several reducing agents to produce these metallic sols and further studied the optical properties and the coagulation behaviour of these colloidal particles. Faraday’s sols were relatively unstable and ranged in colour from purple red to blue and showed that ‘colloidation’ of gold in air or hydrogen gave a precipitate on glass or quartz with an identical red or blue colour as seen in sols. He posited that the ruby glass’s colour was due to the presence of finely dispersed gold particles. He further showed that ‘Purple of Cassius’ could be obtained by the reaction between tin chloride and gold sol.

Faraday also demonstrated that gold chloride could be reduced by heat or by reaction with different reagents like organic matter, tartaric acid, etc. His experimentation led him to the conclusion that in both ruby fluid and ruby glass, metallic gold was present in a finely dispersed state.

A typical experiment by Faraday used an aqueous solution of a gold compound (like $NaAuCl_4$), which was treated with a reducing solution of phosphorous in carbon disulfide. The yellow coloured solution obtained was reported to change to a deep ruby colour within minutes. Faraday concluded that the ruby fluid was gold dispersed in the liquid in a very finely divided form, not visible in the microscopes of the day. It was only about a century later that it was found by electron microscopic investigations that these ruby coloured colloids had an average a size of 6±2 nm (Turkevich et al, 1951). A later high resolution electron microscopic study by Henglein (1985) further revealed that Faraday’s fluid preparations contained a distribution of particle sizes (3-30 nm).

Faraday carried out an extensive research to explore the properties of thin films of metallic gold. These films were of great interest to Faraday because of their interesting property of appearing gold in colour by reflected light, but green in transmitted light.

In addition to the gold leaves, Faraday’s second set of specimens included ‘gold’ fluids ranging from ruby to blue to purple colours. Interestingly, the blue and purple fluids settled rapidly. An optical examination later revealed that even the ruby fluids which did not settle, and appeared clear, would disperse light when a thin beam of sunlight was passed through them. So, here was the conundrum on Faraday’s hands: the *solution-like* fluids appeared clear and did not settle over time, but *suspension-like* fluids which do settle, dispersed light.

Faraday continued his work on both sets of his specimens - films and fluids. By March 1856, he was convinced that the films and the fluids were both gold in an uncombined state. He found that the colour of the deposited film was not dependent on the film thickness. His studies on application of mechanical pressure on the films revealed that the colour of the film was dependent on the mechanical disposition of the particles of the film. Interestingly, his observations on the action of heat and chemicals made him wonder if the manifested colour of the films were dependent on their size and shape.

By July 1856, Faraday had concluded that the green appearance of the films was due to the presence of elongated particles. And among the blue and red fluids, he found the blue fluids to contain larger particles. The green colour was specifically seen when some force operated to elongate the otherwise symmetrical particles.

Interest in colloidal gold peaked in the last quarter of the 19th and the beginning of the 20th century with the development of Zsigmondi's invention of the ultramicroscope by Zsigmondy (1909) and Mie's (1908) theoretical explanation for the colour of colloidal gold.

Historical experiments as pedagogical tools

Researchers have long been fascinated with the replication of scientific historical experiments (Chang, 2011 and references therein). Historical apparatus and the replication process hold epistemological currency. Work done from a pedagogical perspective as well, emphasises the relevance of historical scientific experiments. Notable in this latter category is Alchin's incorporation of historical experiments into an innovative interdisciplinary science course for non-majors (Alchin et al, 1999). Harold White (2001) made good use of Stoke's spectroscopic study of the irreversible oxidation and reduction of hemoglobin (published in proceedings of the Royal Society London in 1864) to teach concepts in biochemistry. The current paper follows White's PBL methodology, and as mentioned earlier, is presented as a PBL plan to be implemented.

Some considerations on setting up this PBL

For this PBL plan to be successful, the students are required to be conversant with concepts in UV-visible spectroscopy, colloid chemistry and the basics of quantum mechanics. But this isn't necessarily a problem because the syllabi of most postgraduate chemistry programmes (in the country) are structured such that by the time students are introduced to *nanoscience* as a separate course in the final year, they have already taken up the aforesaid pre-requisite courses in the preceding semesters. However, the PBL can be preceded by a quiz/ questionnaire to evaluate students' knowledge of the underlying topics and if necessary, revise them.

The PBL plan proposed here envisages this issue of the pre-requisite knowledge on the students' part and thus requires them to come up with a Learning Issues List (forthcoming section in the paper). The intention here is that once the instructor is made cognizant of what the students identify as difficulties, the instructor would then address these very issues in the class. The lectures here in the PBL mode, if any, are thus on a need-to-know basis.

Unlike a lecture-based teaching, PBL would require the instructor to play many roles, not just limited to moderating discussions. But that said, the PBL learning track offers students ample time and room to develop their critical thinking skills, for they aren't being fed with knowledge here, but are constructing it for themselves with able mentoring. And perhaps, this isn't too far-fetched to say that with all their questioning, hypothesizing and coming-up with plausible answers backed by previous knowledge in the subject, we might just be inculcating and developing in our students the tenets of reasoning and rational thinking.

For students as well as for instructors, the change from the lecture-based style of teaching to PBL could be fraught with uncertainties. This is where technology can be used to their advantage; the use of a free learning management system like google classroom could indeed be a great help here. For a small class size, on such a platform the instructor can check on the research articles each student has collected, comment on their relevance, suggest better sources of information etc., thereby ensuring that the students come well-prepared for the class activities. Additionally, appropriate video/podcast links could also be shared with the students to help them with their problem-issue(s) as and when they arise. Assignments may be evaluated online such that the class time is freed-up for fruitful discussions. Also on platforms like these, the instructor has the option to invite another PBL expert, perhaps in a different corner of the world, more experienced in the subject/PBL implementation to oversee the proceedings and/or offer their input. Such hand-holding might just help the instructor in the initial days so that they gain confidence to steer the PBL plan along.

But is there a downside to PBL? Are the students made to bear an additive cognitive load here? And what about those students who naturally shy away from active participation in group discussions? Perhaps there are no easy answers to such questions. The purpose of education remains to make students think. Thinking, questioning and discussions are the cornerstones of PBL. Perhaps if this bigger picture and its significance is impressed upon the students, and their curiosities are whetted enough, it wouldn't be pollyanna to expect them to walk the path with their instructor.

Setting the stage for Faraday's article for PBL

Faraday's classic synthesis of gold colloids may be demonstrated to the students or a video of it may be shown. This exercise will inform them of the basic crux of Faraday's paper. Having seen the experiment, the students may be assigned the article to read before the next class with the fair warning that they might not understand it on the first read. Students may be advised to make notes as they read the article, and be encouraged to refer to other sources of information pertinent to the topic.

The PBL plan

1. Learning issue list

An essential component of PBL is for students to identify what they know and more importantly, what they don't know. To enable students in this identification, they may be asked to come up with a list of ten learning issues (specific concepts that they did not understand in the article). These lists may be collected from all the groups in the class and evaluated to assess what instruction the students need to solve the issue at hand.

2. Learning issues report

For a PBL implementation to be successful, students must go beyond their resources at hand to pursue knowledge from other sources in between their group meetings. Students may be encouraged to come up with a short paper (one page) summarising their grasp of the issue at hand based on their perusal of various references. It may be noted that the first and the current item on the student assignments are individual activities and are important to steer the students and their respective groups towards a productive discussion.

In the context of Faraday's paper, some pertinent issues that might come up are with his use of archaic chemical names and mass denominations. More important dilemmas may arise concerning the different colored fluids seen by Faraday.

3. Laboratory manual assignment

Once the students have moved beyond the topics in their learning issues (which should have been discussed in class in their respective groups with inputs by the instructor) they are now assigned the task to come up with a protocol of the experiments in Faraday's paper. They may be asked specifically to list the various reducing agents employed by Faraday in his synthesis of gold sols. Students should be asked specifically to denote the reactions via balanced chemical equations. Group discussions may then be focused on the underlying principle of these equations.

Specific input from the students may also be sought on the effect of heat and mechanical pressure on the gold sols as described by Faraday.

It is envisaged that students might find this part of the assignment difficult and this is where the instructor may step in and explain the chemistry at work after a perusal of the students' assignments.

An entire class hour may be devoted to this exercise as this is where students get to analyze what they understood from their reading of Faraday's paper and what is the chemistry involved in the experiments.

4. The concept of Surface Plasmon Resonance (SPR)

It is now known that the beautiful ruby-red colour of the gold colloids is due to a rather narrow absorption band at 520 nm. If in introducing Faraday to the class, his experiment was replicated, then a UV-Visible absorption spectrum of the reaction product may be obtained to be shown in the class. Alternatively the 520 nm SPR peak from literature may be used for this purpose.

It may be emphasised that the presence of this peak in the UV-Visible spectrum denotes the presence of gold particles in solution. A discussion may also be carried out on the shift of this peak as a function of nanoparticle size (i.e., as dependent on colours observed by Faraday). The SPR band is established to be affected by the particle size (Link & El-Sayed, 1999).

This may be a good time to delve in particular detail about the usage of the word nanoparticle as opposed to Faraday's usage of "ruby fluids" and "sols". It may also be pertinent to bring in Graham with his ideas and introduction of the word "colloid" in scientific literature. Depending on the curriculum and the lesson plan, this may also be good point to segue into a historical development of *nanoscience*, and the breakdown of classical mechanics in moving from bulk to nanomaterials. It may be noted that this move towards the nano regime results in the emergence of markedly different properties in matter compared to its bulk counterpart.

5. The optical properties of gold nanomaterials

Presenting his findings to the Royal Society, Faraday remarked: "*It is probable that all gradations from blue to ruby exist; for the production of which I can see no reason to imagine any other variation than the existence of particles of intermediate sizes or proportions".* It is thus seen that Faraday hinted at the size-dependent properties of his metallic sols. Today it is known that the properties of gold nanoparticles are indeed dependent on their size, shape and composition.

The SPR, which results from photon confinement to small particle size, enhances all the radiative and nonradiative properties of the nanoparticles, thereby enabling them to be used in a variety of applications (Huang El-Sayed, 2010). Mie theory explains the SPR band intensity and wavelength and its dependence on factors affecting the electron charge density on the particle surface such as metal type, particle size, shape, structure, composition etc. A foray may be made into Gans theory which predicts that when the shape of the gold nanoparticles changes from spheres to rods, the SPR band is split into two.

Summing up

The traditional approach to teaching, which is predominantly teacher-centred, most often reduces education to a transfer of information from the teacher to the student (Mazur, 2009). In PBL however, the teacher plays the role of a facilitator. PBL, with its student-centric approach focuses on the processing and application of information. PBL has proven to be an effective method to enthuse chemistry students towards an active participation. If students are given an authentic and challenging problem with the input of timely guidance, they are more likely to evince an interest towards the subject, thereby enjoying the learning process. With PBL, students stand to develop their higher order thinking skills, which contributes to their overall scholastic development. With the use of classic research articles, students can not only get an intellectually stimulating problem scenario, they could also gain a historical perspective as they begin to weigh the various developments in the time line of the scientific field as relevant to the problem at hand. With the use of such PBL set-ups, it is hoped that students not only gain a qualitative understanding of the chemical concepts, but learn to bridge the *'gap'* between real-world chemistry and curricular chemistry.

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ENLIVENING THE TEACHING AND LEARNING OF CHEMISTRY

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A teacher of chemistry in a residential school found that most of her students expressed disinterest in the subject, citing it as 'a difficult subject' with too much to remember. This paper is an account of the year-long action research that she undertook to draw them into learning the subject with interest and enjoyment. The researcher began with a survey of 500 teachers' and students' views on what makes any subject interesting, why chemistry is deemed to be 'tough' and what students look for in a teacher/ an interesting class. This led to a deeper understanding of the causes of disinterest and typical expectations of students from a teacher, which then gave way to the design and implementation of various strategies to make chemistry meaningful. By the end of the cycle of action research, not only did the students begin to enjoy learning chemistry, but also there was much learning for the teacher.

Background

Considerable work has been carried out in exploring difficulties commonly experienced by learners of chemistry. Reid (2007) connected these learning difficulties to the way the human mind processes new information. He used a new learning model to bring home the need to take note of how much the working memory is being loaded. Sirhan's (2007) overview of research carried out over the past few decades on learning difficulties (experienced by school as well as university students of chemistry) also has suggestions for enhancing interest and motivation. Humerick's (2002) action research study (an approach that was adopted in the current work too) has emphasized inquiry and collaborative learning. Avargil et al (2012) have delineated four understanding levels of chemistry, and have advocated context-based chemistry as a way of increasing interest levels.

It was against this backdrop that I undertook to conduct action research (AR). I have generally found that most students have a mental block towards chemistry as they deem it to be the 'toughest subject', 'difficult to understand', and 'taking a great deal of time to learn'. So, I began my AR with a tentative expression of the issue thus: "lack of interest in students for chemistry, due to fear of subject." My AR was facilitated by a teacher educator[1] who runs her own teacher development enterprise. Several teachers of my school have been facilitated in their AR by this facilitator, who has been visiting our school every month for three years now. During each of her monthly visits, the facilitator would observe one of my classes and later share her observations with me in face-to-face meetings. We also corresponded over email in between her visits.

[1] The facilitator has a doctorate degree in chemistry and two decades of teaching experience.

Framing the AR problem

My facilitator led me through a process of thinking about the problem more deeply, after which my AR problem changed as below:
"To motivate my students with a love for chemistry so that they begin to learn on their own."

My facilitator then led me through a process of analyzing this problem. My impressions about the subject were similar to those of my students, back in my XI and XII grades. Coerced by my family, I then took up chemistry as one of the subjects in my undergraduate program, but remembered feeling scared about the subject. But, in the first year of my B.Sc. program, I experienced a chemistry teacher who taught interestingly by using different strategies and connected the subject with real life examples. His teaching left a lasting impression on me, and was responsible for developing my interest, self-confidence and belief in learning chemistry. Now, I was eager to investigate why students of today did not like chemistry. I began interviewing teachers and students, using a self-designed questionnaire. I planned to interview 500 people, only 200 of whom would be in the school that I work in. Knowing the time constraints of people in other institutions, I could not hope for a face-to-face interview with those outside my school. Therefore, I deliberately designed the questionnaire to be open-ended. The results of the survey are described later.

I began to realize that motivating my students with a love for chemistry - so that they begin to learn on their own - was a rather tall order. So, with the help of my facilitator, I began breaking down my larger goal into smaller, achievable objectives:

"To eliminate the fear from students' minds towards chemistry and inculcate an interest in the subject."

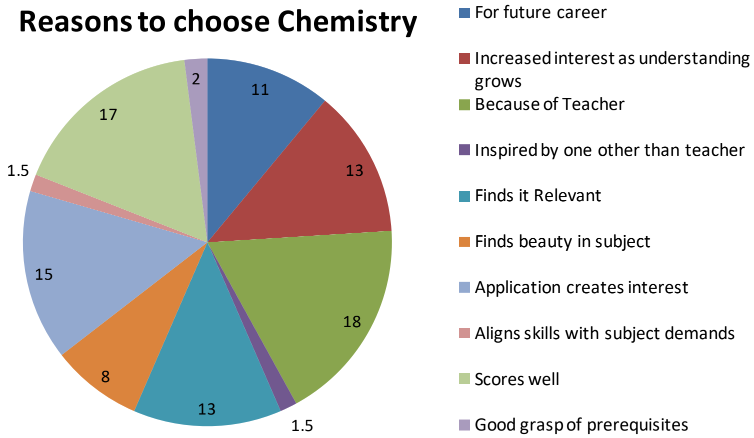
In order to analyze the reframed problem, I conducted interviews of approximately 500 people (students as well as teachers), to understand various causes of fear in students towards chemistry. I prepared two different questionnaires for students and teachers. The former probed students' reasons for liking/disliking any subject, opting for/dropping chemistry and listing out the difficulties faced by them in learning chemistry. Drawing from my own student-day experiences, a question about when they feel comfortable/uncomfortable with a teacher was included here. In my questionnaire for teachers, I explored the teachers' expectations of a student, what made her/him most satisfied while teaching; her/his guesses for why students drop a subject and the teacher who had inspired her/him the most.

Broad summary of findings

I interviewed 30 teachers and 470 students - of which 309 were from XI and XII grades of different schools. From the data obtained, I prepared a pie chart as shown below. The main findings from the top four sectors of the pie chart are:

- The highest percentage (18%) of students who like chemistry do so because of their teacher.
- The second highest percentage (17%) like it because they score well in the subject.

- The third highest percentage (15%) of students like it because application of their learning has created interest in them.



- And the fourth highest sector (13%) like it either because they find it relevant, or because their interest grows as they understand it better and better.

This reaffirmed my own experience of the teacher playing a vital role in sparking interest in the student. I also began to see that students' interest can be sustained if they can see the relevance and applicability of the subject in their own lives.

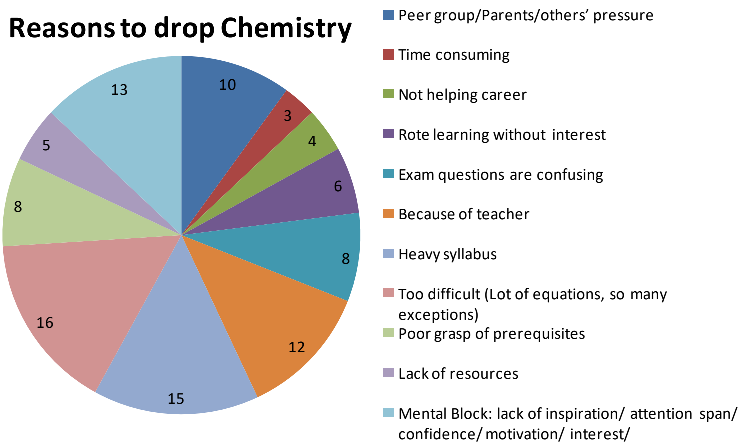
I knew of instances where students opt for chemistry and later drop the subject. So, I then analyzed the reasons why students drop the subject. From the pie chart below, it can be seen that:

- The highest percentage (16%) of students who drop chemistry do so because of difficulty in remembering numerous equations as well as exceptions to every rule.

- The second highest percentage (15%) drop it because of the heavy syllabus.

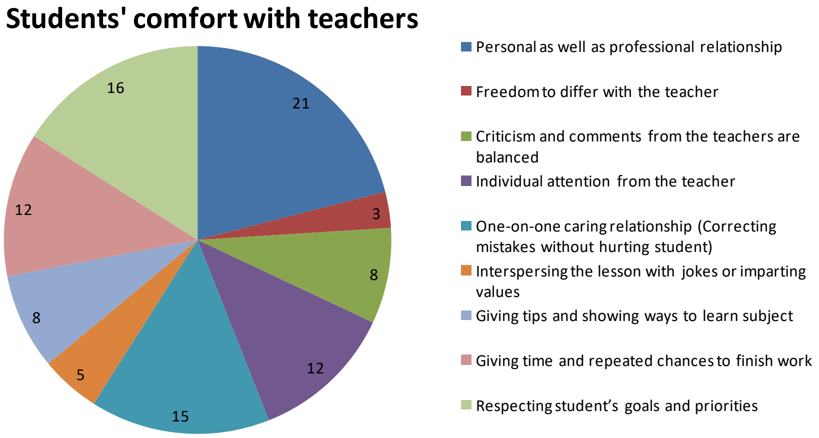
- The next highest percentage (13%) drop it because of mental block: lack of inspiration/ attention span/ confidence/ motivation/ interest.

- The fourth highest (12%) drop it because of the teacher.



Interestingly, this survey revealed that the teacher was not as critical in spurring students to drop a subject as she/he is to get them to like it! Here, it is the way that the subject is perceived that gets students to drop it.

I now collated the results of my efforts to find out *what makes students comfortable with their teachers*. The results are shown in the pie chart below.

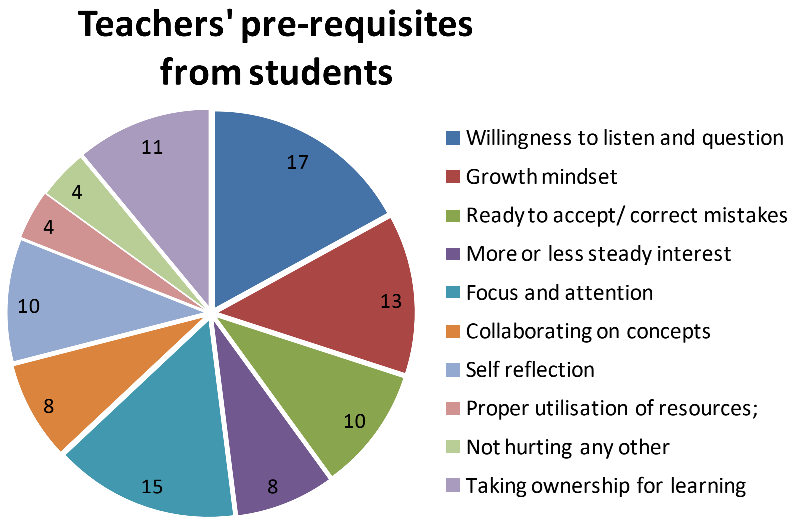


Here it is evident that:

- The highest percentage (21%) of students feel comfortable with teacher when they can maintain personal as well as professional relationship.
- The second highest percentage (16%) of students feel comfortable with a teacher who respects students' goals and priorities.
- The next highest percentage (15%) of students feel comfortable with the teacher when there is a one-on-one caring relationship (correcting mistakes without hurting students' sentiments) is built and maintained.
- And 12% of students feel comfortable with the teacher who gives them individual attention, as well as time and repeated chances to finish their work.

From the above findings, I gained the understanding that it is not enough if I care for my students: they should perceive that I care for them. Further, I identified that it was important to understand what makes teacher-student interactions comfortable, not just from the students, but also from the perspective of the teachers and gauge their expectations from the students. Here, I found (see pie chart below):

- The highest (17%) prerequisite expected by teachers is students' willingness to listen and question.
- The second highest (15%) prerequisite is for students to focus and be attentive in class.
- The third highest (13%) prerequisite is student' growth mindset: their participation, interest, responsiveness and enthusiasm to learn, logically think and perform mental calculations.



- The fourth highest (11%) prerequisite is students taking ownership for their own learning.

I also collated the findings from a set of questions that served to explore teachers' perceptions of their roles – apart from just teaching their subject. Some of the findings were that many teachers (19%) perceived their role (other than subject teaching) being able to sensitize students to reflect. The second highest percentage (14%) of teachers perceived their role (outside subject teaching) as giving a chance to students to express their creativity, and collaborative, analytical and critical thinking skills. An equal percentage (14%) of teachers perceived their role as helping to build life skills (like emotional stability) in their students, and they stated that they should give students tips for cognitive thinking, critical thinking and critical analysis. The fourth highest percentage (13%) of teachers perceived their role to include the teaching of moral values (truthfulness, humaneness, moral values, ethics, etc. and respecting the student and the subject.

The responses in the survey and interviews indicated that along with subject teaching, a teacher should: i) bring out the abilities of the student to learn the subject, and ii) create comfortable situations to motivate them and give them confidence. Overall, I learned that instead of simply holding certain expectations from students, teachers should equip students to meet the prerequisites for learning the subject. Having analyzed the reasons why students fear the subject and are disinterested in it, I now went on to the third step of AR: i.e. Identification of strategies to tackle the problem.

Identification of strategies

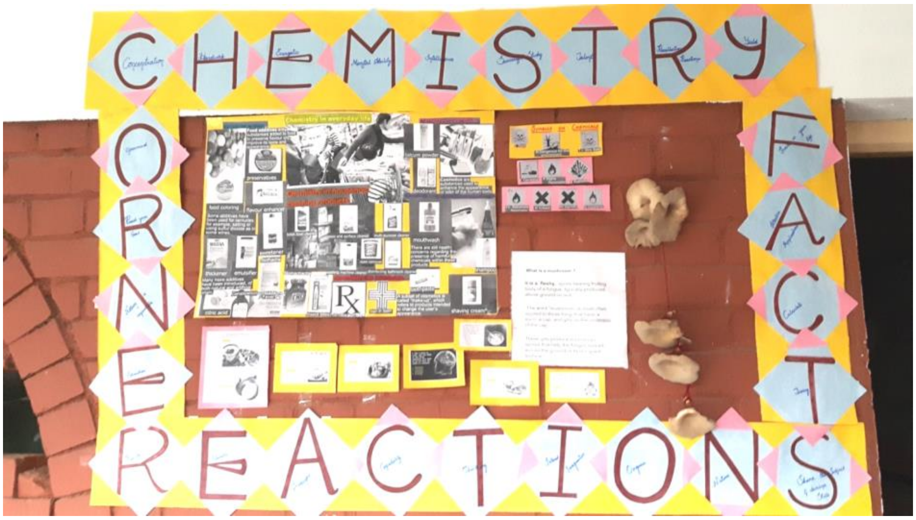
Slowly, I came to realize that there are so many ways by which students can enjoy learning. Each subject has its own flavour. So, I wondered, why can't we help students learn chemistry concepts through enjoyable stories and activities? When I shared this with my facilitator, she narrated a story with which she usually begins her first chemistry class. She said that she excites her students' interest by telling them of a metal that is so highly reactive that we cannot touch it with our hands – it has to be stored under oil. She then tells them of a non-metal which is a gas at room temperature and which is so poisonous that it was used to kill the enemy during the Second World War. Yet, when this metal and poisonous non-metal combine, they produce something which we simply have to add to our food daily: else, we will declare the food to be tasteless. If this is not magic, she asks, what is? This is chemistry! I was struck by this novel way of describing the formation of sodium chloride and indirectly demonstrating to the students, the need for studying chemistry. From these findings - as well as from the guidance that I received from my facilitator after her observations of my classes - I selected appropriate strategies to make chemistry interesting. I highlight some of these strategies here:

Methods to teach subject		**Methods for creating interest/ motivating students**
1) Providing opportunity for student to guess/ research a solution or new topic – Student-centred teaching, from known to unknown		1) Encouraging students' innate abilities gives confidence
2) Breaking up complicated concepts into smaller and easier ones, and providing basic information so as to allow them to then find the rest on their own		2) Displaying willingness to listen to students' questions, at the same time clarifying doubts clearly and appreciating their openness to ask questions
3) Clear explanation of the basics and giving extra information that is not found in the text book		3) Giving them chances to express their creativity and to collaborate: by involving them in seminars, making drawings/ charts/ power point presentations/ working or non-working models, etc.
4) Making connections between topics, and from a topic to real life situations, highlighting applications of concepts in daily life		4) Conducting games/quizzes, making puzzles related to the subject
5) Practical work/ demonstrations/ videos		5) Asking students to do their own documentation
6) Creating and narrating stories based on characteristics of elements/compounds as well as moral stories; sharing inspiring, true stories of achievements and hard work of scientists		6) Developing self-evaluation skills in students
7) Interactive ways of learning such as discussions/debates, drama/ role play/ mono acting on some topics		7) Taking students out on field trips

Implementation of selected strategies

1) I arranged a 'Chemistry Corner' and prepared a chart with pictures on the use of chemistry in our day-to-day lives. Every day, I raised questions related to the importance/ presence of chemistry in our lives. Eg. (a) which chemicals are used in the synthesis of perfumes in order to have pleasant aroma? (expected answer: esters)

   E.g. (b): You must have experienced shedding tears while cutting an onion. This is due to the presence of .... (answer: Sulphur in the onion cells).



   As I kept changing the questions every day, I also added some word building exercises related to element symbols. E.g.: C Ar B O N. Soon, I found some of the students discussing the likely answers amongst themselves. So, I hoped that their curiosity was getting aroused.

2) To teach the differences between physical and chemical changes to class IX students, I divided them into teams and asked them to collect a minimum of ten different things from within the school premises. Then I assigned two 'collectors': one each for collecting the results of physical changes and chemical changes. After discussion for which item belonged to the 'physical change collector' or to the 'chemical change collector' and why, each team brought that item to the respective 'collector'. During the discussion, I supported/corrected their conclusions with my reasons for doing so. By the end of this activity, they were able to list almost all the properties of physical and chemical changes. Finally, we consolidated all the points in writing. Even after class, I noticed them discussing whether the things around them represented a physical or a chemical change.

3) To make sure that students learn the basics that demand usage of their memory, I would conduct quizzes. E.g.: To learn symbols of elements, valencies of ions, chemical formulae of compounds, etc. I would set one group to question the other group. While they questioned others, I noticed that they tried their very best to recall a maximum number of answers. As they discussed the answers within their groups, I also saw that the student who did not know the answer slowly came to learn.

4) I then conducted role plays to distinguish between molarity, molality, and mole fraction in Class XII. Each student played the role of one of these terms – while an anchor asked questions, that role player introduced herself/ himself and also explained how s/he differed from the rest.

5) Students of grade IX prepared their own powerpoint presentations and presented seminars in class; some even prepared a chart of the entire periodic table on their own.

Reflection

I concluded my research by identifying which teaching methods the students had found to be most effective and why. The overall findings were that many preferred audio-visual methods over lectures, and several students acknowledged that their attitude towards chemistry had started changing. The effect of the strategies reflected in their grades as well. I came to see that I was slowly achieving the objectives of my AR. After eight months, at the end of the second term, I asked my formerly disinterested students a few questions about their current opinions on chemistry. Their answers - which were as follows – led me to conclude that my AR was a step in the right direction.

Questions	**Answers**
How did you feel about chemistry at the beginning of the year?	Confusing subject; very hard to learn; I don't like it; I don't have hopes that I can do it because it is very difficult to understand.
What do you feel about chemistry today?	I understand the subject now, I improved, I can do it, but I didn't work hard; now whatever I read, I am able to understand; I like it; good; it has become easy for me.
Why has it changed?	I'm able to understand it better; basics are clear; easy to work on that; I scored marks even in chemical reactions in which I couldn't last year - because I understand them now.

Acknowledgments

I wish to thank Mrs. Sunanda Ali, Principal, The Peepal Grove School for supporting this research work and Dr. Neeraja Raghavan, Founder Director, THINKING TEACHER, for facilitating my action research.

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PROBING STUDENTS' UNDERSTANDING OF QUANTUM MECHANICAL EIGENSTATES AT TERTIARY LEVEL

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Quantum mechanics (QM) is one of the core subject areas in the undergraduate physics curriculum and it is usually taught in an abstract framework. Visualization of concepts such as energy eigenfunction and its shape, probability density etc. helps students to have a deeper understanding of QM. In this study, we attempt to explore the challenges faced by undergraduate students in visualizing the concepts of eigenstates for a given potential distribution. The research was carried out in a qualitative framework and the investigation revealed alternate conceptions in understanding of eigenfunctions. Specifically, the results showed difficulties students face in associating eigenfunctions with prescribed boundary conditions in a potential distribution.

Introduction

Quantum mechanics (QM) plays a crucial role in the development of various branches of modern physical sciences along with their applications. Introduction of fundamental concepts in QM begins at the undergraduate curricula and in general, it is taught in an abstract and mathematical framework. It is therefore assumed that the students attain a suitable level of mathematical ability for appreciating the formulations alongside their first level course on QM, or they are well acquainted with them before the course begins. However, several studies in the area of physics education research (PER) show that the students face difficulty in understanding various aspects of basic QM which include probabilistic interpretation of particle location (Bao, 2002), concepts related to probability density (Singh, 2008), measurement in QM as well as time-development of quantum states (Johnston, 2007) and many more (Styer, 1996; Ayene 2011). This is in addition to the difficulties students face in understanding the mathematical framework (Wuttiprom, 2009; Goswami, 2011).

An alternative plausible route for improving basic understanding of QM and its application in the undergraduate curricula, would be to assist students towards visualizing the concepts (Ayene, 2011). The process of visualization of relevant features of basic QM could facilitate a qualitative appreciation of non-trivial experimental outcomes (Cataloglu, 2002; Goldberg, 1967). In addition to its impact on students majoring in physics, the visualization of relevant aspects of basic QM problems would be immensely helpful for students majoring in chemistry (Tsaparlis, 2009).

It has been often found that the visualized models for appreciating QM concepts strongly interfere with the visual frames existing with them for understanding topics in classical mechanics or electromagnetism (Carr, 2009). At times, this results in over-simplification of problems and inappropriate understanding (Paoloni, 2007). For example, the domain of QM considers probabilistic representations to be fundamental to the understanding of physical world, which is contrary to the deterministic view dictated by classical physics. The strong interference of thoughts is an important source for development of alternate framework of concepts in QM (Cataloglu, 2002; Oslen, 2010).

Although research in the area of alternate conceptions in QM has generated some interest in the Indian context, there is an ever-growing need and open questions, which require comprehensive investigation and discussion. The present curriculum, which is followed in most of the Indian Universities and institutions of higher learning, deals with QM alongside classical mechanics. Moreover, the topics in mathematics such as differential equations, Fourier analysis and probability are essential ingredients for appreciating QM formulation. Given this scenario, the students' understanding undergoes rapid transformation during their first course on QM and the visualization is strongly affected by their understanding of classical mechanics and mathematics. In particular, the concept of 'energy eigenfunction' for an eigenstate in a potential well is a completely quantum mechanical concept without a classical counterpart. Students, at times, tend to borrow classical ideas for conceptualizing the 'energy eigenfunction', which results in alternate conception. It could well be anticipated that the visualizations, which could be comfortably accommodated into their concepts of classical mechanics such as dependence of force experienced by a particle on its potential energy, would exhibit lesser degree of alternate conceptions. However, the visualization of more involved concepts such as relationship between energy eigenfunction and particle's motion, impact of boundary of potential well on energy eigenfunction etc. could exhibit more diverse understanding and possibly, more misconceptions.

Research Objectives & Methodology

The aim of the present study is to investigate and understand students' conceptualization in terms of visualization of quantum mechanical eigenstates by undergraduate students in an Indian institution of higher learning. We primarily carry out an in-depth study of how students visualize 'energy eigenfunctions' or 'wavefunctions' of a given state in a potential well and connect it to their already existing ideas. In order to fulfil the objective, a qualitative approach was adopted in which a tool (see Appendix) comprising three questions (Q10, Q11 and Q17) of QMVI[1] (Cataloglu, 2002) in the form of a written test was administered to 10 students (S1 to S10) of a government-aided institute excelling in teaching and learning of basic sciences. The choice of QMVI is essentially motivated by its content compatibility with institutions of higher scientific learning in India as well as its focus on testing the visualization of QM ideas. QMVI is a multiple choice questionnaire in which the students are asked to provide the correct choice as well as a plausible reason behind the choice so as to ascertain their existing mental models. At the time of taking the test, the students had credited two courses on QM (1 basic level and 1 advanced level). In addition, all the students are reasonably familiar with basic numerical methods and computational recipes required for solving problems in basic QM. In the written test, the students were also asked to provide a reason for choosing an option. Based on the written responses, all the students were interviewed in detail for ascertaining the pathways, which were adopted for solving the problems. The students' interviews were transcribed and analyzed from a constructivist perspective with an underlying assumption that each individual constructs his/her own knowledge based on their previous experience (Mintzes, 2005). The primary objective of this study is to bring out the core issues

[1] The QMVI tool could be accessed by writing to Prof. R. Robinett at rick@phys.psu.edu

encountered by the students in visualizing the concept of energy eigenfunction.

Data Summary

Q10, Q11 and Q17 broadly required the knowledge of standard practices in QM for obtaining energy eigenstates when a potential function (*V*) is defined. These questions additionally required an idea of graphical representation of eigenfunction for given eigenstate. In particular, Q10 inquired about the possible energy eigenfunctions of a state whose energy (*E*) is less than 'V_0' where 'V_0' the potential of a rectangular potential barrier as shown in the figure (see appendix). The students needed to visualize the solution of Schrödinger's equation when energy $E < V_0$ and hence, make a connection to the graphical representation of the mathematical form of eigenfunction. Written responses of the students distinctly showed the difference in visualizations made by students while they concretize a picture from a mathematical expression. For example, the mathematical expression representing the energy eigenfunction would comprise of an amplifying as well as a decaying solution within the potential barrier, and most students at undergraduate level in a physics classroom acknowledge this crucial point. However, when it is required to visualize, most of them are of the opinion that 'either' of an amplifying 'or' a decaying solution is the correct representation which would essentially depend upon the direction of incidence (towards $-x$ or $+x$) of the particle. Table 1 summarizes the responses given by students.

Q no.	**[a]**	**[b]**	**[c]**	**[d]**	**[e]**
10	1 **	2	5	1	1
	(S5)	(S2,S4)	(S3,S7,S8,S9,S10)	(S1)	(S6)
11	0	2	4 **	3	1
	-	(S3,S10)	(S1,S4,S7,S8)	(S2,S5,S6)	(S9)
17	3 **	0	3	3	1
	(S4,S5,S8)	-	(S1,S2,S7)	(S3,S6,S9)	(S10)
**** Correct response**					

Table 1: Summary of students' responses to Q10, Q11 and Q17 from QMVI

In the interview, S2 and S4, who chose option (b), argued that the solution of Schrödinger's equation would always be oscillatory irrespective of potential distribution. After having a re-look at the problem during the interview, S4 said that he did not notice the boundaries at '$x = a$' and '$x = b$' and figured out option (b) to be the correct one in the written response. Now, he changed his response to correct option (a) after acknowledging his mistake. Similarly, S2 could also identify her mistake of not considering boundaries and subsequently, she changed her choice to option (a) which contains both amplifying and decaying solution. However, she remained clueless as to why an oscillatory function (with decaying envelope) cannot be an energy eigenfunction (see Appendix). Four students (S3, S7, S8, S9) who chose option (c) mentioned that they explicitly assumed the particle (with energy *E*) to be incident from left to right of the potential barrier which would result in an exponentially decaying energy eigenfunction with maximum at '$x = a$' and minimum at '$x = b$' (Fig. I). However, in the interview, all of them appreciated that the particle could be incident from right as well and therefore, a decaying solution from right (Fig.

II) could be a plausible representation of eigenfunction. So, for all of them, either of the figures I or II is an appropriate solution, but “not both of them” simultaneously. Since, there was no option such as ‘either I or II’, the obvious choice became ‘I only’ which was option (c). S10 expressed his inability to obtain the mathematical expression representing the energy eigenfunction and hence, guessed an answer without any particular reasoning behind the same. For S1, the particle is being incident from left on the potential barrier and therefore, energy eigenfunction ‘must’ have a decaying envelope from boundaries ‘$x = a$’ to ‘$x = b$’. In response to Q10, S6 found figures I and II to be definitely correct as they conform to the mathematical solution of the Schrödinger’s equation for the potential barrier. In addition, he mentioned that an oscillatory variation of the solution (Fig. III) is also possible due to existence of ‘excited’ states in potential barrier. When probed further, he asserted that the ‘excited’ energy eigenstates in the potential barrier resemble the energy eigenfunctions for finite potential well. The argument presented by S6 reveals that some students may associate the concepts of quantization and discrete energy eigenstates to any situation where quantum mechanical formulation is applied. The written as well as verbal responses for this question suggested that the manifestations dictated by the mathematical formulations are not always accepted in the prescribed form by students.

The next question (Q11) was aimed at bringing the correlation between energy eigenstates and eigenvalues as well as visualization of energy eigenfunctions in an infinitely deep potential well (see Appendix). The students were probed to ascertain the impact of imposing boundary conditions on energy eigenfunctions. The interviews with S3 and S10 revealed that the rigorous classroom practice of imposing boundary conditions in “two” boundaries of a one-dimensional infinite well had a deep-rooted impact on them. When the problem demanded that the boundary condition is to be imposed at one boundary only, they found difficulty in correlating their previous understanding in a holistic sense and hence, could not ascertain the possible alteration of energy eigenfunctions. They were of the opinion that the solution, inevitably, has to go to zero at the infinite-well boundaries as it is practiced in classroom. In the process, it became apparent that the students, in a few occasions, gave marginal importance to the interdependence of energy eigenfunctions and eigenvalues. Amongst the students who chose correct option (c), the explanation provided by S8 markedly differed from the reasons provided by other 3 students. According to him, the Schrödinger’s equation is being solved ‘numerically’ which renders the solutions to be ‘non-exact’. Therefore, from the viewgraphs representing possible eigenfunctions, Fig. III is not possible as he reckons it to be an exact solution. Although, he does not pay much attention to the requirement of imposing boundary conditions and statements, he finds Fig. I & II to be possible eigenfunctions as they do not go to zero on the right boundary. This, he thinks, is essentially due to ‘*error in numerical computation*’, which is the most crucial aspect of numerical simulation. All the students (S2, S5 & S6) choosing option (d) were unanimous with the view ‘energy eigenvalue can never be less than energy in the ground-state of infinitely deep potential-well’. Any change in boundary condition, will not make it possible to have feasible eigenvalues, lower than the ground-state eigenvalue. In addition, S2 asserted that the energy eigenfunction should have a signature of ‘sinusoidal’ wave pattern as the solutions are ‘sine’ waves with respect to $x = 0$ (left boundary). However, she thinks that the energy eigenfunction represented in Fig. II never crosses zero and hence, may not be sinusoidal at all. According to S6, the particle will not be able to move if energy of the particle becomes lesser than the ground-state energy. When probed further, he brings in classical concepts and argues that the system (infinitely deep potential well) will draw all the energy from the particle, thereby limiting its motion. Surprisingly, the same three students (S2, S5 and S6) did not find the energy eigenvalues important enough while investigating the possibility of an appropriate energy eigenfunction represented by Fig. III of the question. After scaffolding, all the three students agreed upon the role played by the boundary conditions, however it was only S5 who added that Fig. II could also represent a correct eigenfunction. On the other hand, S9 who found none of the figures as well as descriptions to represent an appropriate solution, discovered during the interview that he missed the point which leads to 'non-zero value of eigenfunction' at the right boundary ($x = L$) and accordingly, found all the statements to be incorrect. Finally, he mentions that statement I is the only correct assertion and not statement II. This is mainly because, he thinks, energy less than ground-state energy is not possible which is similar to the arguments provided by S2, S5 & S6.

Question no. 17 (Q17) of QMVI typifies a few problems in QM which requires visualizing a problem from altogether a different perspective of symmetry associated with the problem and its manifestations. Although, shape of the potential function in the question requires complex mathematical treatment for ascertaining the eigenstates, the symmetric potential function provides an alternate route to visualize the actual solution without performing rigorous mathematical exercise. In this particular problem, a symmetric potential function is halved by inserting an infinite wall at the centre and the question asked for the modification in the set of energy eigenvalue due to this alteration (see Appendix). In order to obtain the correct answer, the students needed a prior knowledge that the energy eigenfunctions corresponding to a symmetric potential well would be symmetric and anti-symmetric about the centre of well. This concept is extensively discussed in a classroom context as well as in standard textbooks (Griffiths, 2004). Also, they needed to appreciate that the energy eigenfunction would go to zero at a boundary where potential goes to infinity, thus leading to survival of only certain energy eigenstates. However, the adoption of this route is not obvious at an undergraduate level who, mostly deal with rigorous mathematical solutions as a classroom activity. Therefore, it is to be expected that a few students who are familiar or students who have come across such an approach, which is based on symmetry considerations, would be able to obtain a solution without delving into mathematical intricacies. Indeed, the written responses of students conform to our expectations, which are described below.

In the interview, S1, S2 and S7 showed unanimity is expressing that the solution to this problem could only be found by rigorously solving the Schrödinger's equation and implementing the boundary conditions so as to obtain the correct eigenvalues. However, they acknowledged that the involved mathematical complexities deter them to adopt such a tedious route and therefore, they think that the solution remains unchanged if potential function is halved. S1 and S7 further justified their choice by pointing to the symmetric and linear variation of potential with respect to space (x). According to them, even if half of the potential well does not exist, the potential function still remains a linear function of x and hence, the solution of Schrödinger's equation would remain unchanged. However, when the role-played by boundary condition in determining the quantization of states was being discussed with both of them (as a scaffolding tool), they modified their viewpoint and explained that the energy eigenfunctions as well as energy eigenvalues would change. In spite of this, both of them were unable to ascertain the kind of change in the eigenvalues as a result of alteration in energy eigenfunction. Similarly, students (S3, S6, S9) choosing option (d) were also quite uncertain about their approach. S10 (who chose option (e)) confessed to have made a guess in this question, as he had no clue regarding the approach to solve this problem and found the complex mathematical route to be the only plausible way out. S3, however, said that he had solved a similar problem before which he was unable to recall. Interestingly, S6 asserted that the probability of finding a particle would remain same even if the potential function is halved and hence, the energy eigenfunctions corresponding to different eigenstates would remain unaltered. Therefore, the 'particles' from one side of the potential function (which does not exist anymore after an infinite potential wall comes at $x = 0$) would come to the other side, leading to doubling of eigenvalues. According to him, this would happen because the particles would add up their energy to the existing particles on that side. When he was further probed on the concepts connecting energy eigenvalues, potential function and probability, he could not come out with a logical explanation for 'probability remaining same' and 'eigenvalue alteration'. As per his understanding, QM essentially deals with energy of particles and their behaviour when they are subjected to a potential variation. However, it is quintessential to acknowledge that QM essentially provides a systematic description about the distribution of energy eigenstates (levels) and their eigenfunctions in a system defined by a potential distribution (Griffiths, 2004). Similarly, S9 finds it extremely difficult to obtain a rigorous mathematical solution to ascertain the answer but anticipates that there would an alternate route based on symmetry considerations. He acknowledges that the energy eigenfunctions would alter due to modification in boundary conditions. However, it was quite difficult for him to connect the symmetry associated with potential function to the eigenfunctions or energy eigenvalues. S10, on the other hand, asserts that the energy would be halved when the potential function is halved and hence, the choice of option (e). According to him, the total energy of a particle is a function of potential energy plus kinetic energy and there is 'no information' about kinetic energy, therefore, the total energy associated with a particle is simply dictated by the potential function. Hence, if the potential function is halved, the total energy is halved or energy of particle would be halved.

Research Outcomes & Conclusion

This research attempted to delve into students' conceptualization and visualization of the fundamental quantum mechanical concept of energy quantization and its dependence on boundary conditions. Students' constructs were investigated through their visualization of the related concepts using QMVI (Cataloglu, 2000). It was found that students had made varied interpretations of similar concepts and a significant fraction was found out to be alternate as compared to well-accepted interpretations within the discipline. The most important misconceptions revealed through the study are as follows:

- Energy eigenstates are always associated with physical particles and their distribution/dynamics (motion) determine the energy eigenfunction
- Energy of particles present in a system determine the eigenfunction for the system
- Solution of Schrödinger's equation always results in oscillatory eigenfunction
- Energy eigenvalues and eigenfunctions are not related to each other
- Energy eigenstates for a given potential well cannot be altered by changing the potential or its boundaries
- Quantum mechanical formulations necessarily describe distribution and dynamics of particles

In many situations, it was evident that classroom experiences of students strongly influenced their understanding of new problems. This observation supports the very basic assumption of constructivism that new knowledge is built on the previous knowledge (Tobin & Tippins, 1993). Therefore, novel questions in some instances were understood as well as interpreted in terms of known problems. Students tended to rote learn or remember the prescriptions or algorithms but forgot to pay attention to the involved nuances or intricacies. Even if the students came across slightly divergent conditions, they still resorted to the prescribed algorithms and at times, even refused to consider the point of divergence, claiming that it is not possible. For example, in Q11, both S3 and S10 expressed that the boundary condition has to be applied at both the boundaries even if the question categorically stated that the boundary conditions were to be applied on one boundary only. On a similar note, in response to Q17, S3 mentioned that he was not sure about the solution, because he does not remember the recipe of solving a similar problem in class. A manifestation of classroom practice was also evident in response of S3, S7, S8, and S9 in Q10 where they always considered 'direction' of incidence of particle on a potential barrier. This question (Q10), however, intended to investigate the students' understanding about solution of Schrödinger in case of a potential barrier (with boundaries) and hence, did not require knowledge about 'direction' of incidence of particle (Griffiths, 2004). This observation indicates that it is quintessential for teacher to explicitly demonstrate the consequence(s) of imposing boundary conditions on the basic nature of quantization in a quantum mechanical treatment. A major concern was noted in case of S6 (while responding to Q17), where the conceptualization of primary idea behind quantum mechanical formulation was alternate with respect to the fundamental basis on which QM stands. She mentioned that the distribution of energy levels (energy eigenvalues) will be essentially dictated by the energy of particles present in the system (or potential-well) which clearly indicates an inappropriate understanding of fundamental principles of QM. As per foundation of QM, change in a potential distribution in space brings in redistribution of energy eigenstates (or energy levels) and particle redistribution takes place accordingly (Griffiths, 2004). S6 considered the problem in an incomplete framework. It suggests that teaching emphasis could be on making students appreciate the fundamental as well as philosophical aspects of QM, not only quantitatively but qualitatively as well. The observations above give a substantial reason for teachers to explore what students conceptualize. In order to deal with this particular conception, it becomes imperative to exert specific emphasis on single particle behaviour in broad variety of potential distribution.

In conclusion, this research was an attempt to add a qualitative dimension to the studies related to understanding of fundamental concepts in QM. Through this study, we have been able to elucidate a few mental constructs, which hinder the appropriate conceptualization of energy eigenfunctions and its dependence of boundary condition. Consequently, this study is aimed at helping physics teachers to design their pedagogy for a more meaningful learning environment while teaching QM at the fundamental level.

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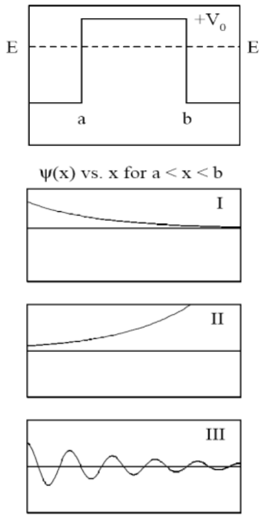
Appendix

Q10) The figure on the right indicates a particle of energy E near the boundary of a 'step up, then down' or a rectangular barrier potential located between $x = a$ and $x = b$ as shown, with $0 < E < +V_0$. If you solve the time-independent Schrödinger equation in the region (a,b) using this potential and this energy, which of the wavefunctions shown below the figure, could you find?



(a) *I* and *II* only

(b) *III* only

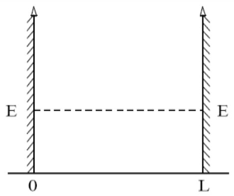
(c) *I* only

(d) *I* and *III* only

(e) *I*, *II* and *III* are all possible

Q11) You are given a computer program which is designed to solve the time-independent Schrödinger equation (TISE),

$$-\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} + V(x)\psi(x) = E\psi(x)$$



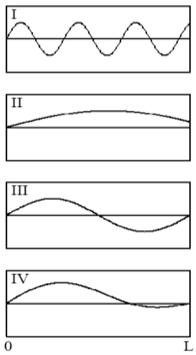
for a particle inside the infinite well shown in the figure above (defined by impenetrable walls at $x = 0, L$ and with $V(x) = 0$ in between) for any value of $E > 0$. The program finds solution to this particular TISE which also satisfy the boundary condition $\psi(0) = 0$ and outputs wavefunctions in graphical format. A convenient reference value of energy is defined to be $E_{REF} = \hbar^2\pi^2/2mL^2$. Consider the following statements about the waveforms I-IV (on the right panel) shown below the potential variation.

I. You could get Fig. I as output for some value of $E >> E_{REF}$

II. You could get Fig. II as output for some value of $E < E_{REF}$

III. You could get Fig. III as output for $E = 2E_{REF}$

IV. You could get Fig. I as output for some value of E



Which of these statements is (are) true?

(a) III and IV only

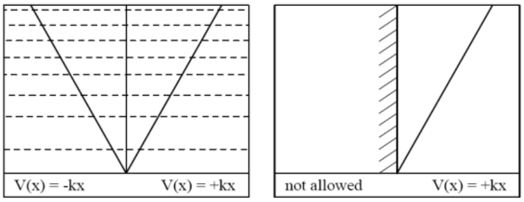
(b) III only

(c) I and II only

(d) I and III only

(e) None of them are true

Q17) The picture on the left shows a one-dimensional potential energy function given by $V(x) = k|x|$ (solid lines) as well as the eight lowest allowed energy eigenstates (dashed horizontal lines). These energies are given, in terms of energy Ɛ, by the values



E = (1.0, 2.3, 3.2, 4.1, 4.8, 5.5, 6.2, 6.8 ...) Ɛ

The plot on the right shows the 'half-well' version of the potential, namely that given by,

$$V(x) = \begin{cases} \infty & for\ x < 0 \\ kx & for\ x > 0 \end{cases}$$

so that the potential is the same for $x > 0$, but the particle is not allowed in the region $x < 0$. The most likely pattern of energy eigenvalues in the 'half-well' on the right is given by

(a) E = (2.3, 4.1, 5.5, 6.8, ...) Ɛ (b) E = (1.0, 3.2, 4.8, 6.2, ...) Ɛ c) E = (1.0, 2.3, 3.2, 4.1, ...)(Ɛ)
(d) E = (1.0, 2.3, 3.2, 4.1, ...) (2Ɛ) (e) E = (1.0, 2.3, 3.2, 4.1, ...) (Ɛ/2)

EXPLORATION OF STUDENTS' UNDERSTANDING OF VECTOR ADDITION AND SUBTRACTION

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Physics problem-solving requires many-layered attributes, robust training in using mathematical tools, being an important one. Vector concept is one such tool which has important application in physics, as several physical quantities are represented as vectors. Problem-solving process and problem solution are critically dependent on the correctness of relevant vector operations. In this paper, we report student responses to problems involving vector addition and subtraction in two dimensions. We have selected a few questions from the test of understanding vectors (TUV) and a few have been formulated by us. Results show dominant difficulty in vector addition that is reflective of students' weak understanding of the geometrical arrow representation. Results also indicate an enhanced difficulty level for vector subtraction, in agreement with research work reported earlier. Students do use the ijk representation with ease in vector addition and subtraction.

Introduction

Problem-solving is used both as a teaching aid and diagnostic tool in physics education. Physics problem-solving is a reasoning process which requires the use of qualitative and quantitative knowledge towards constructing a rational solution. From a learner's perspective, a structured and coherent knowledge organization in physics is essential for effective learning and problem-solving. Considerable research has been done towards understanding the difficulties encountered in problem-solving from a learner's perspective. It appears that problem-solving ability is not guaranteed by mere learning of content and vice-versa. Physics instructors and their instructional strategies need to build problem-solving skills which focus on the application of relevant physics concepts in a given context and develop robust mathematical skill sets which strengthen the learners' problem-solving abilities (Reif, 1995; Larkin & Reif, 1979; Larkin, 1981; Knight, 2004; Hegde & Meera, 2012; Heuvelen, 1991; Leonard et al, 1996; Reif et al, 1976; Hegde & Meera, 2011).

Most of what is discussed below is in the context of Indian undergraduate education. The traditional approach to teaching physics at the college level involves classroom lectures and problem-solving activities confined to very few end-of-chapter problems. Though the students possess sufficient mathematical training, their ability to do the math in the physics problem context is poor. Our earlier research was to understand the learners' approach to this task and the microstructure of processes towards construction of the solution (Hegde & Meera, 2011, 2012; Shubha & Meera, 2015b). Physicists have investigated the difficulties in the application of mathematics knowledge to physics contexts (Bollen et al, 2016; Pepper et al, 2012; Nguyen & Rebello, 2011a). Problem-solving ability gets impeded as a result of improper/inadequate training in the use of mathematical tools (Patrick & Finkelstein, 2008; Nguyen & Rebello, 2011b).

In this study, we take a deeper look at how learners use a math tool, specifically vectors. Though students come with a good familiarity of vector algebra/vector calculus tools, their ability to use them in the context of physics problem-solving needs understanding. Vector concept is an important tool to understand the physical quantities in mechanics, electricity and magnetism; containing directional information in addition to magnitude. In recent years, several researchers have investigated students' understanding of vector representations in solving problems. Studies have shown difficulties learners possess in using vector representations with or without a physics context (Knight, 1995; Nguyen. N & Meltzer, 2003; Flores, Kanim, & Kautz, 2004; Shubha & Meera, 2015b; Deventer & Wittmann, 2007; Barniol & Zavala, 2014a; Barniol & Zavala, 2014b; Gire & Price, 2014; Heckler & Scaife, 2015; Wutchanal et al; 2015). Researchers have also enunciated the approaches to statistical data analysis of responses to multiple choice questions, the approaches classified are based on the purpose and the algorithm used (Ding & Beichner, 2009). Physicists have used the Classical Test Theory to evaluate Brief electricity and magnetism assessment (L. Ding, 2006) and Test of understanding Vectors-TUV (Barniol & Zavala, 2014a).

The study intends to probe the conceptual and procedural knowledge of basic vector operations. In this work, we report results of students' understanding of simple operations using vectors.

Methodology

For this study, we have used the Test of understanding vectors (TUV) module developed by Barniol and Zavala in 2014. This is a standard 20 item test in MCQ format, used for the assessment of basic concepts in vector algebra. In our study, respondents of the pilot assessment of TUV are 74 students from first year graduate course, MSc (Master of Science) in physics at Department of Physics, Bangalore University. Students were facilitated to complete the test individually at their own pace. The data was analysed and the analysis of the responses enabled us to formulate our additional questions on the chosen vector concept. The framed questions consisted of MCQs and free-ended questions, either with or without a physics context. As the responses are only indicative of the general nature of student difficulties, we propose to follow this pilot study by taking interviews of a few students to understand the nature and origin of difficulties.

In this communication, we have analysed students' responses to three test items numbered 1, 11 and 13 of TUV. Item 1 tests the students' understanding of vector addition, item 11- the negative of a vector multiplied by a scalar and item 13 - vector subtraction, all in 2 dimensions. Other questions analysed are those framed by us which complement the responses to the TUV questions. We have also performed the statistical tests which focus on individual test items of TUV by calculating the item difficulty index and item discriminatory index.

The respondents who participated in this activity did have familiarity with alternative methods of vector representation - the arrow with/without reference to a coordinate system and were also adept at basic vector operations. Their vector algebra and vector calculus learning is fairly exhaustive. With a rationale of understanding how they use a vector representation in a given context, we conducted the following activity.

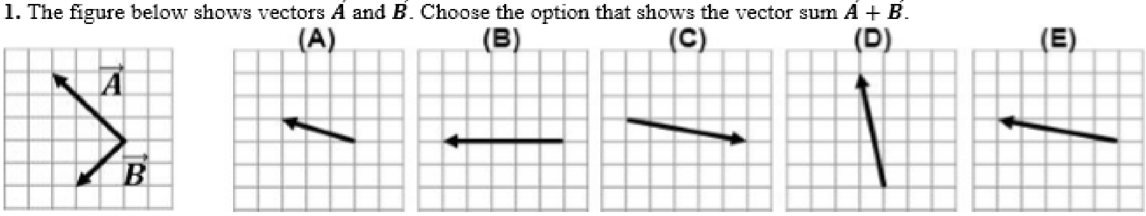
Results & Discussion

As discussed earlier, we used the TUV diagnostic test. We analyse the responses that illustrate their understanding of vector addition/ subtraction in the arrow format. As these questions are in the MCQ format, responses in general, may not reveal the underlying thought process in choosing an option. However, they tend to serve as pointers for a semi quantitative analysis. Also, for the chosen questions, we have estimated the item difficulty index which is a measure of the difficulty of a single test question. We have also calculated the item discrimination index (by adopting the 25 % bracket of low and high scorers' method) (Ding et al, 2006). It measures the extent to which a single test item distinguishes students who know the concepts from those who do not.

The first of the selected questions (Item 1 in TUV) is produced below.

Test of Understanding of Vectors (TUV)

1. The figure below shows vectors $\vec{A}$ and $\vec{B}$. Choose the option that shows the vector sum $\vec{A}+\vec{B}$.



Students are required to calculate the sum of two vectors represented on the grid. In our study, about 94 % of the students were unable to choose the correct option. Figure 1 shows the responses of students.

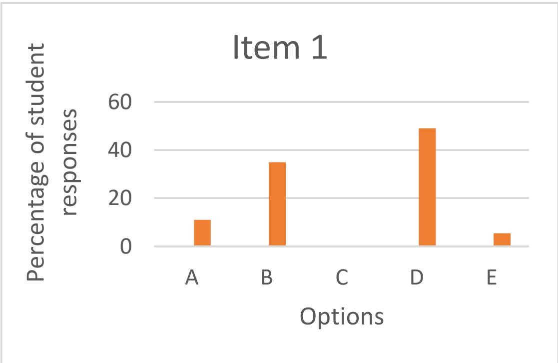
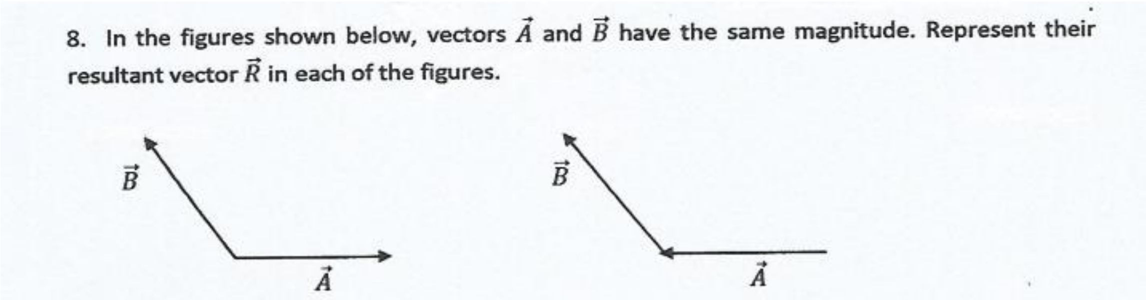


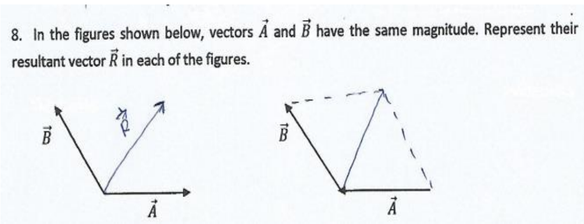
Figure 1: Percentage responses to item 1 of TUV

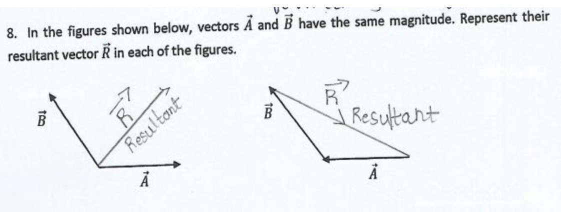
About 6 % have selected the correct option E whereas 49 % have selected the incorrect option D (tip-tip vector) and 35 % option B (vector that bisects the two vectors). This result of ours differs from the result reported by Barniol & Zavala (2014a) and Heckler & Scaife (2015). Barniol & Zavala (2014a) report 74 % students of introductory physics course chose the correct option to Q1 in TUV. Heckler & Scaife (2015) report total scores of students (I sem or II sem) of introductory physics course on the vector addition condition (79 %). The item difficulty index for the same being 0.055 in our study, is suggestive of the question difficulty. The percentage of correct responses is not as high as one would expect for a relatively simple task to the advanced learners. The low discriminatory index of 0.1053 shows that, the item does not have a satisfactory discriminatory power.

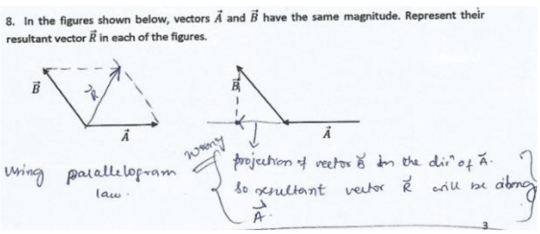
Our students learn arrow representation of a vector as the introductory step in learning the vector concept, more often without the underlying grid format. What follows is the learning of algebraic operations. The resultant vector (equivalently, sum of two vectors) can be found using the parallelogram law. The responses in our activity clearly show a tendency of the students to opt for the tip-tip choice. To validate this conjuncture, we gave the following problem to students. Care was taken to formulate the question in-line with familiar representation style.

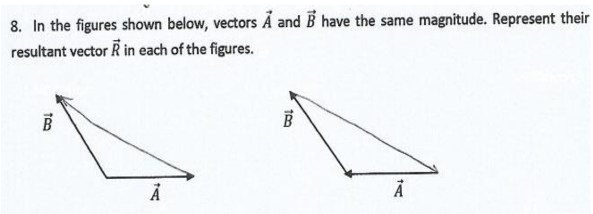


Some illustrative responses of students are provided below.









57 % represented the resultant vector correctly by using what is learnt as the parallelogram law of addition and 38 % represented the resultant correctly by using the triangle law of addition. The confusion to use the addition laws is real. The problem involving arrow representation seemingly prompts the students to use the geometrical construction procedure, though wrongly.

An increased percentage of correct response to this problem compared to item 1 of TUV could be due to the familiarity with the learnt arrow representational format.

An alternative approach to item 1 would be to represent the vectors in the procedurally simpler *ijk* format. Addition then, procedurally mimics an algebraic addition. Research has also shown that learners adopt the *ijk* representation with ease (Heckler & Scaife, 2015). It is surprising that students, though familiar with use of *ijk* format, did not use it while answering item 1 of TUV. What could be lacking is the understanding of the correspondence between the arrow representation on a grid and the *ijk* format. The absence of the explicit coordinate axes may have deterred them from writing the vector in the *ijk* format. To validate the ease of using the *ijk* format, we provided the students with the following problem.

Problem: Consider vectors $\vec{A}=3\hat{\imath}+2\hat{\jmath}$ ***and*** $\vec{B}=2\hat{\imath}+\hat{\jmath}$***. Find the resultant vector.***

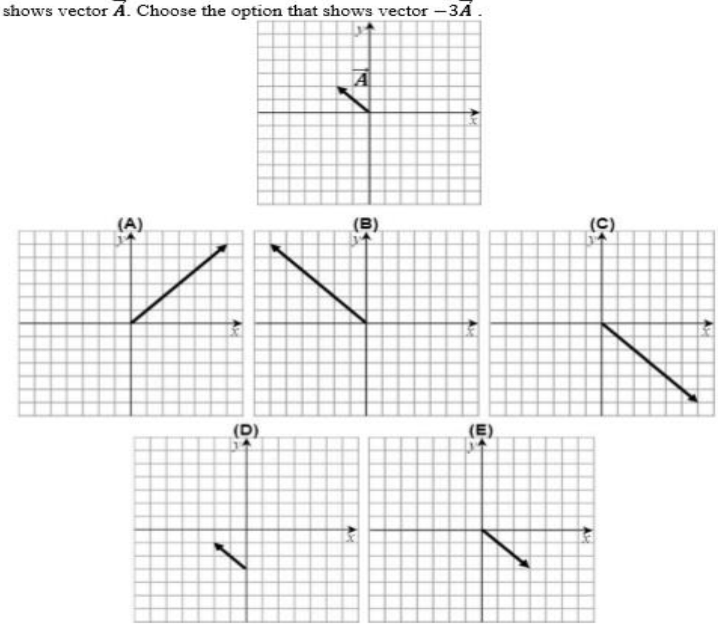
52 % of students calculated the vector sum correctly. We observed a significant increase in the percentage of correct responses in the *ijk* format in comparison to the arrow grid format, though not high for the relatively simple task. Students may not see the operations of finding the sum and resultant of two vectors as same (with reference to item 1and the problem).

The high difficulty level of item 1 can be attributed to various factors. Our own research on representing forces on charges in a two-charge configuration has shown the students' difficulty in applying the procedural knowledge even for drawing the appropriate vectors (Shubha & Meera, 2015b). The vector representation takes myriad forms starting from the basic arrow format in space to the most general tensor format; with arrow on a grid, arrow in a specific coordinate system, the unit vector component form i.e. *ijk* form etc as the intermediate stages. An important aspect of instruction is to enable the learner to use a new representation correctly and to do the associated operations robustly. The present practice of a cursory introduction to a new representation appears to compound their difficulty of understanding and its usage and hence influence students'problem-solving process in situations that employ the notion of vectors.

The arrow representation does appear to generate more difficulties than the *ijk* representation. This brings us to the discussion of the necessity of teaching the arrow representation. Indeed, the arrow representation that works for the 2D case cannot be used for representation in higher dimensions. However, the *ijk* representation cannot be introduced without the reference to the coordinate axes. To be able understand *ijk* notation, (not merely as a rule of the game), requires a familiarity of the concept of unit vectors along defined axis directions. An introduction of the arrow representation on a grid or a coordinate frame in the initial learning stage is inevitable. Training in the translation between the *ijk* format and arrow format results in the much-needed practice for loosening the rigid structures learners possess and promotes the practice of restructuring.

The second selected question (Item 11 in TUV) which is intended to probe the understanding of negative of a vector is given below.

11. The figure below shows vector $\vec{A}$. Choose the option that shows vector $-3\vec{A}$.



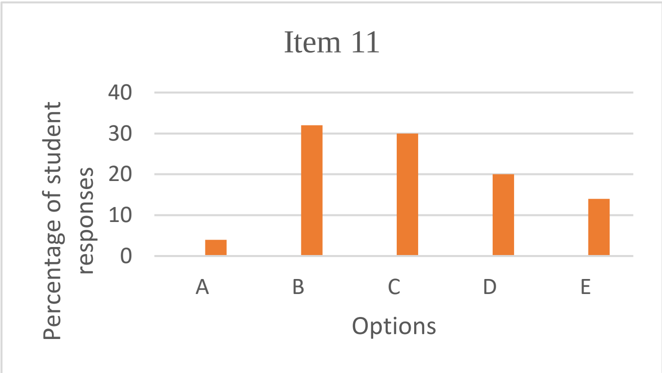
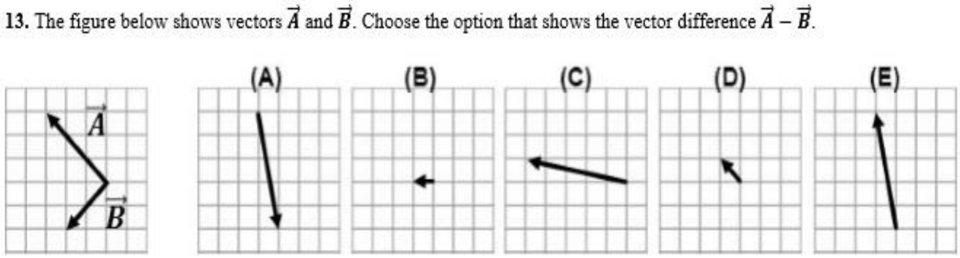


Figure 2: Percentage responses to item 11 of TUV

One basic requirement to perform subtraction is to understand the idea of a negative of a vector. We analyse the responses for the item 11 of TUV. The difficulty index of the item was calculated as 0.30 and the item discriminatory index as 0.47. Figure 2 shows the responses of students. The percentage of correct response C is 30 % and of incorrect response B is 32 %. About 33 % of the students seem not to take cognisance of the negative sign and about 25 % tend to understand negative of the given vector as a vector displaced by three units from the origin.

With the above observed difficulty in representing the negative of a vector, it is interesting to investigate the responses to the problem involving subtraction of vectors. The third selected question (Item 13 in TUV) is produced below.

Item 13 is related to graphical subtraction of vectors in 2D. The students are required to choose the graphical representation which yields the vector difference. Figure 3 shows the responses of students.



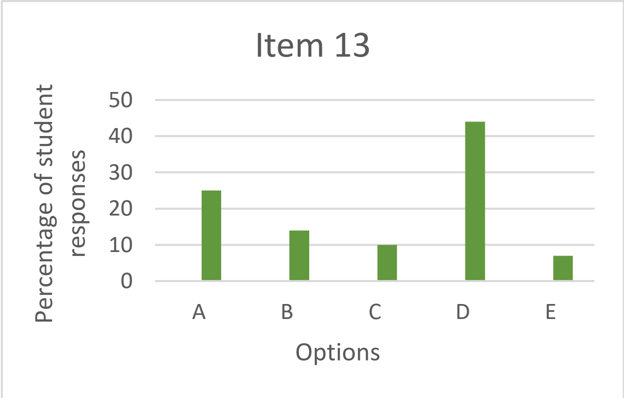


Figure 3: Percentage responses to item 13 of TUV

About 7 % of the students chose the correct option E. About 25 % chose the incorrect option A and about 44 % chose the incorrect option D. A high percentage of students chose option D. The item difficulty index for the same being 0.07 is suggestive of the high level of difficulty. The item discriminatory index for the same is a low 0.158. This reveals the possible adopted procedure as a mere difference of two numbers, without any significance to the direction of the vectors. Barniol & Zavala, (2014) report 56 % students of introductory physics course chose the correct option to Q13 in TUV. Heckler and Scaife (2015) report total scores of students (I or II sem) of introductory physics course on the vector addition condition (57 %), lower than that observed for vector addition. Deventer & Wittman report an overall low performance even in the context of one-dimensional subtraction, 18 % correct in math context and 46 % correct in physics context (isomorphic questions). Wutchanal et al (2015) report a low number of correct responses to a problem on vector subtraction in 2D (Pre-test). An enhanced difficulty in performing subtraction operation is evident even in our work.

We presented the following free-ended question on vector subtraction in the *ijk* format.

Problem: Consider vectors $\vec{A}= 2\hat{\imath} +2\hat{\jmath}$ ***and*** $\vec{B}=-\hat{\imath} +3\hat{\jmath}$***. Calculate the vector*** $\vec{A}$ ***-3***$\vec{B}$***.***

79 % of the students calculated the solution correctly. The *ijk* format prompts algebraic calculations with ease. The use of subtraction notation in contrast to the use of the word resultant (in the vector addition problem) appears to have a positive influence.

It may be argued that the comparison of our results with the results of cited references is not appropriate as the student samples in both are contextually different. The students of our study have learnt the basic concepts on vectors in their 12^{th} grade and revisited the same during their UG course. This study intends to assess the robustness of learning a mathematical representational tool. The procedural understanding of vector operations is not expected to fade with time. Also,we did not adopt the pre-test→intervention→post-test format as the study does not attempt to evaluate the effectiveness of any new teaching / learning methodology.

Conclusion

Our investigation has revealed the students' dominant difficulty with the arrow representation of a vector and the related mathematical operations. An alternative *ijk* representation which mimics the algebraic operations seems to be less complex. A difficulty to identify the context for the applicability of the addition law is evident. Effective learning of vector concepts and their related operations is important for building an understanding and to use them in a problem context. The teaching has to take into cognizance the difficulties students have in understanding a representational format and has to address these issues. Our research shows that such lacunae in their ability to internalise relevant operations are bound to have a negative influence on problem-solving. We further intend to investigate the development and use of a framework to build on the skill sets.

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TEACHING ONE DIMENSIONAL TIME INDEPENDENT SCHRÖDINGER EQUATION USING SPREADSHEET

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In this paper, we use the Numerov method to find the solutions of time independent Schrödinger equation for different cases and graphically plot and interpret wavefunctions or probability densities. Using Excel spreadsheet we have investigated three cases such as Infinite well with a cosine bump, step up and step down potential within an infinite well and sloping potential well. Using spreadsheets is more preferred rather than using advanced packages like Mathematica and Python as it is more commonly used and solving the Schrödinger equation does not require prior knowledge of a programming language. We believe working through these cases will enhance understanding of the shape of the wave function and probability density and improve students' qualitative understanding of Quantum Mechanics.

Introduction

In the traditional course of undergraduate quantum mechanics, students study the analytical solution of Schrödinger equation, which can be solved exactly only for a limited number of cases. A solution of the Schrödinger equation can be more conveniently obtained by using numerical techniques than using analytical techniques. In this paper, we solve the one dimension time independent Schrödinger equation for different potential wells and obtain a numerical solution using spreadsheets. Further, we graphically describe the wavefunction or probability density for each case. Different tools have been utilized to obtain the numerical solution to Schrödinger equation like Mathematica (Schmied, 2015) and Python (Srnec, Upadhyay, & Madura, 2017), but using the spreadsheet is preferred because it is widely used and also an approximate solution to the Schrödinger equation can be obtained without prior knowledge of programming. Although Microsoft excel spreadsheet has been utilized to find the solution to the Schrödinger equation for the Morse potential (Rioux, 1991) and Harmonic Oscillator (Levine, 2014), the cases we have included like the infinite potential well with a cosine bump and one dimensional step potential have not been addressed in these references. These spreadsheets can be used as part of laboratory experiments or assignments for the undergraduate course in quantum mechanics so that the students will develop further insight in the shape of the wavefunction and will develop a qualitative understanding of quantum theory. In the following sections, we describe the method and show how to obtain the numerical solution of the Schrödinger equation for Infinite Square well with a cosine bump, step-up and step down potential in an infinite well, infinite well with an internal sloping potential.

Method

We use the Numerov method to obtain the numerical solution of the one dimensional Schrodinger equation, (Levine, 2014). The Schrödinger equation is

$$-\frac{\hbar^2}{2m}\psi'' + V\psi = E\psi$$

which can be written as,

$$\psi'' = G\psi$$

Where, $G = \frac{m}{\hbar^2}(2V(x) - 2E)$

Consider finite portion which includes the classically allowed region and the ends of the allowed region may also extend somewhat into the classical forbidden region. Divide this portion into small intervals each of length s.To obtain the discretized differential equation we expand $\psi(x)$ into a Taylor series around point x_n involving power of s, we can show that (Levine, 2014)

$$\psi_{n+1} \approx \frac{2\psi_n - \psi_{n-1} + 5G_n\psi_n s^2/6 + G_{n-1}\psi_{n-1}s^2}{1 - G_{n+1}s^2}$$

Knowing the value of ψ_n and ψ_{n-1} we will be able to calculate ψ_{n+1}. To solve the Schrödinger equation with the boundary condition $\psi(x_{min}) = \psi(x_{max}) = 0$, we choose $\psi_0 = \psi(x_{min}) = 0$ and ψ_1 a very small number.

By choosing a trial value of energy, E_r, along with values of ψ_0 and ψ_1 we can calculate the wavefunction for different values of x. If the value of $\psi(x_{max}) = 0$ then the trial value of energy is correct and if $\psi(x_{max})$ is not equal to zero then the process is repeated until we have made the right choice of the trial energy and that value of energy will be equal to the eigenvalue.

We can locate the energy eigenvalues by counting the number of nodes in the wave function. If the wave function ψ contains no nodes between x_{min} and x_{max} then E_r is less than or equal to the energy eigenvalue of the ground state, E_1. If ψ contains one node between x_{min} and x_{max} then the value of E_r is between E_1 and the energy eigenvalue of the first excited state,E_2.To find many eigenvalues it is convenient to use the solver tool in excel, which is explained in the next section,that can vary the value of the trial value of energy till we get the value of $\psi(x_{max}) = 0$,within the required accuracy.

Solving the time independent Schrödinger equation for different potentials

Infinite square well with a cosine bump:

Consider the case of the one-dimensional infinite square well of width a containing a cosine bump, (Eisberg & Resnick, 2014). The potential V is written as

$$V = \begin{cases} V_0 \cos\left(\frac{\pi x}{a}\right) & -\frac{a}{2} < x < \frac{a}{2} \\ \infty & x < -\frac{a}{2} \; or \; x > \frac{a}{2} \end{cases}$$

Where$V_0 \ll \pi^2\hbar^2/(2ma^2)$

The dimensionless reduced energy, E_r and reduced x coordinate x_r can be calculated and is given by,

$$E_r = \frac{E}{\left(\frac{\hbar^2}{ma^2}\right)} \text{ and } x_r = x/a$$

Similarly, reduced potential energy and reduced normalized wavefunction in dimensionless form can also be defined as

$$V_r = \frac{V_0 \cos\left(\frac{\pi x}{a}\right)}{\left(\frac{\hbar^2}{ma^2}\right)} = V_n \cos\left(\frac{\pi x}{a}\right) \text{and} \psi_r = \psi \, a^{1/2}$$

Using all the above reduced variables gives us the dimensionless Schrödinger equation,

$$\frac{d^2\psi_r}{dr^2} = (2V_r - 2E_r)\psi_r$$

Where, $G_r = 2V_r - 2E_r$.

To solve this equation, initial value of $x_r = -0.5$, final value of $x_r = 0.5$, $a = 1$ and $s_r = s/l$ =0.01. Since, $V_0 \ll \pi^2\hbar^2/(2ma^2)$ we have to use the value of $V_n \ll \pi^2/2$. We have chosen the value of $V_n = 0.5$, hence $V_r = 0.5\cos(\pi x_r)$. Following is the procedure of entering parameters in a spreadsheet sheet and using the above mentioned algorithm to obtain the normalised wave function and energy eigenvalues (Levine, 2014),

- Enter the value of $V_n = 0.5$ in cell $B4$, the step size $s_r = 0.01$ in cell $E4$ and the random guess value of the reduced energy $E_r = 0$ in cell $A3$,
- Enter $x_r = -0.5$ in cell $A8$, to calculate the value of V_r and G_r enter the formula $= \$B\$4 * COS(PI() * A8)$ in cell $B8$ and$= 2 * B8 - 2 * \$B\$3$ in cell $C8$.
- Next, to calculate the wave function enter the ψ_0 = 0 in cell D8 and ψ_1 = 1.00E-04 in cell $D9$. To calculate ψ_2, enter the formula, $= (2 * D9 - D8 + 5 * C9 * D9 * \$E\$4\text{^}2/6 + C8 * D8 * \$E\$4\text{^}2/12)/(1 - C10 * \$E\$4\text{^}2/12)$ in cell $D10$.
- The reduced energy eigenvalues can be located by counting the number of nodes in the wavefunction. To do that, enter the formula,$= IF(D10 * D9 < 0, 1, 0)$in cell $E10$. This formula will enter the value "1" in the cell if the wave function values in $D10$ and $D9$ will have opposite sign, which signifies that there is a node between the x_r values in the cell $A9$ and $A10$. To obtain the total number of interior nodes enter the formula =$SUM(E10{:}E106)$ into the

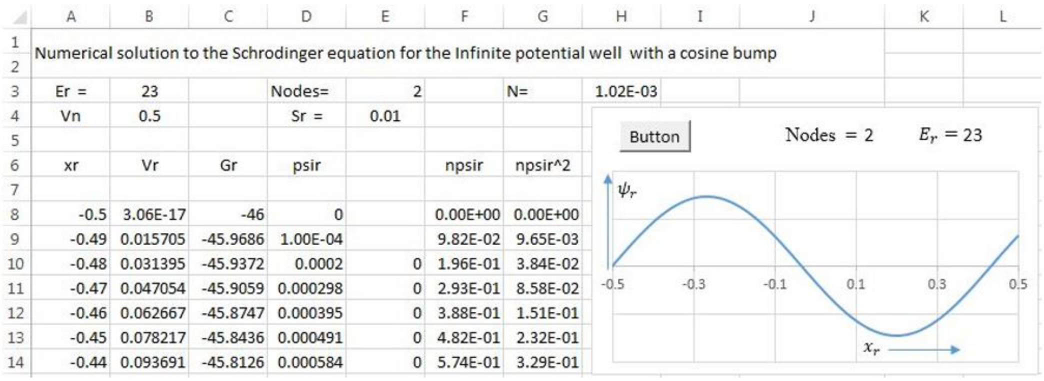
cell $E3$.

- Eigenvalues can be found by trial and error method, described in (Levine, 2014), in which the value of E_r can be varied till we get $\psi(x_{max}) = 0$ (i.e. cell $D107 = 0$) and by counting the number of nodes of the wave function we can know the obtained energy eigenvalue, E_r, corresponds to which Eigen state. Eigenvalues can be found faster by using the solver tool in Excel. In the data tab click the Solver icon (Solver tool might have to be added in if the icon is not in the data tab) and in the set objective box enter D107, next click on the option "Value of" and enter "0". In the option, "By Changing Variable Cells" enter B3 and click solve. The solver tool will vary the value of energy E_r(cell B3) till the value of $\psi(x_{max}) = 0$ (i.e. cell $\$D\$107 = 0$). After you click on solve, the value of E_r obtained is the ground state eigenvalue if the number of nodes is zero. If you increase the value of E_r(cell $\$B\$3$) till the number of nodes is one, the value of E_r obtained after using the Solver tool will be the eigenvalue of the first excited state.

- To normalize the wave function we use the normalization constant given by the equation,

$$N = \left[\int_{-\infty}^{\infty} |\psi_r|^2\, dr\right]^{-1/2}, \text{where} \int_{-\infty}^{\infty} |\psi_r|^2\, dx_r \approx \sum_{i=1}^{100} \psi_{r,i}\, s_r$$

Enter the formula $= (SUMSQ(D9{:}D108) * \$E\$4)\text{^}0.5$ in cell $H3$ and formula $= D8/\$H\$3$in cell F8 to obtain the normalized wave function. Column F will contain the normalized wave function if$E_r$is the energy eigenvalue. Also, enter the formula $= F8\text{^}2$in the cell G8 to obtain the probability density. Next, the normalized wave function and probability density can be plotted against x_r. The snapshot of the excel file is shown in the Figure 1.



	A	B	C	D	E	F	G	H
1	Numerical solution to the Schrodinger equation for the Infinite potential well with a cosine bump							
2								
3	Er =	23		Nodes=	2		N=	1.02E-03
4	Vn	0.5		Sr =	0.01			
5								
6	xr	Vr	Gr	psir		npsir	npsir^2	
7								
8	-0.5	3.06E-17	-46	0		0.00E+00	0.00E+00	
9	-0.49	0.015705	-45.9686	1.00E-04		9.82E-02	9.65E-03	
10	-0.48	0.031395	-45.9372	0.0002	0	1.96E-01	3.84E-02	
11	-0.47	0.047054	-45.9059	0.000298	0	2.93E-01	8.58E-02	
12	-0.46	0.062667	-45.8747	0.000395	0	3.88E-01	1.51E-01	
13	-0.45	0.078217	-45.8436	0.000491	0	4.82E-01	2.32E-01	
14	-0.44	0.093691	-45.8126	0.000584	0	5.74E-01	3.29E-01	

Figure 1: Spreadsheet for Numerov method solution for the Infinite Potential Well with a cosine bump.

- One can create an animation to show the variation of ψ_r as E_r goes through an eigenvalue. To do so, go to the Developer option in the menu bar; click on the insert tab and choose the option "Button" and place it on the graph. In the pop-up window, click on new and enter the code given below (Anand, 2009):

Declare Sub Sleep Lib "kernel32" (ByValdmMilliseconds As Long)
Sub Button1Click()
Dim iAs Integer
For i = 0 To 200:

```
Range ("B3").Value = i
Application.Calculate
 Sleep (100)
Next
End Sub
```

Next, close the window and to start the animation click on the button placed on the graph (Figure 1).

Figure 2 shows the wave function for the first three bound states which are found by numerically solving the Schrödinger equation. The lowest three energy eigenvalues are found to be $E_r = 5.3590, 20.0786$ and 44.7407. The energy eigenvalues are obtained by using the relation, $E = E_r(\hbar^2/ma^2)$.These values can be compared to the energy values obtained by analytically solving the Schrödinger equation. The possible values of E obtained by analytical calculations are (Eisberg & Resnick, 2014),

$$E = \frac{n^2\pi^2\hbar^2}{2ma^2} + \frac{8V_0}{3\pi} = \left(\frac{n^2\pi^2}{2} + \frac{8V_n}{3\pi}\right)\frac{\hbar^2}{ma^2} = E_r\frac{\hbar^2}{ma^2}$$

Where, $E_r = \left(\frac{n^2\pi^2}{2} + \frac{8V_n}{3\pi}\right)$

The lowest three dimensionless reduced energy values obtained from analytically solving the Schrödinger equation are $E_r = 5.3592, 20.1636$ and 44.8376. The reduced eigenvalues obtained are in agreement with the reduced energy eigenvalue obtained by the Numerov method and the slight error observed is due to the approximation of the Numerov method.

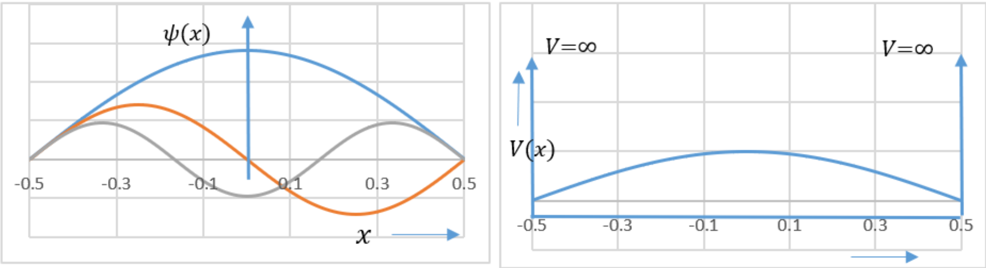


Figure 2: The bottom figure shows the shape of the infinite potential well with a cosine bump and the top part of the figure is a plot of wave function for the first three Eigen states obtained by numerically solving the Schrödinger equation using Excel spreadsheet.

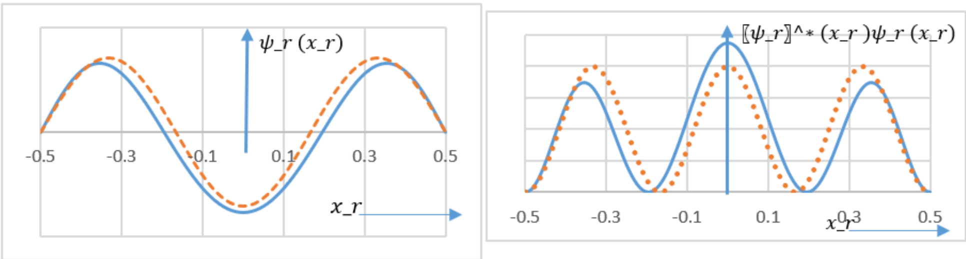


Figure 3: The bottom figure shows the plot of the wave function for the second excited state and the top part of the figure shows the probability of the second excited state for the case of a particle inside an infinite well with a cosine bump (Solid line) and an infinite well without a cosine bump (dashed line).

Figure 3 shows the plot of wave function and probability density of the second excited state for the case of a particle inside an infinite well with and without a cosine bump. To see a more prominent difference in the probability densities of the two plots, we have increased the value of potential to $V_n = 40$ and used the solver tool to obtain the wave function and probability densities of the second excited state for both the cases.

As can be seen in the figure, for the case of particle inside an infinite well with a cosine bump the amplitude of the probability density increases towards the center of the well when compared to that of the case of particle in an infinite well without the bump and the probability density decreases away from the center of the well. Also, the wavelength of the wave function increases towards the center of the well implying that the value of the kinetic energy is less at the center.

One Dimensional Potential step inside an infinite well

Consider the step potential inside an infinite square well:

$$V(x) = \begin{cases} 0 & if x_r \leq 0 \\ V_0 & \text{if } 0.5 > x_r > 0 \\ \infty & \text{if} x_r \leq -0.5 \text{ and} x_r \geq 0.5 \end{cases}$$

Case 1: Energy greater than the potential, $E > V_0$

Consider the case where the energy of the particle in the box is greater than the potential, $E > V_0$and particle is incident on the step up, Figure 4a and step down potential, Figure 4b. We convert the Schrödinger equation in dimensionless form and the value of the reduced potential energy function is chosen to be, $V_r = 100$ and the intervals were taken as, $s_r = 0.01$.

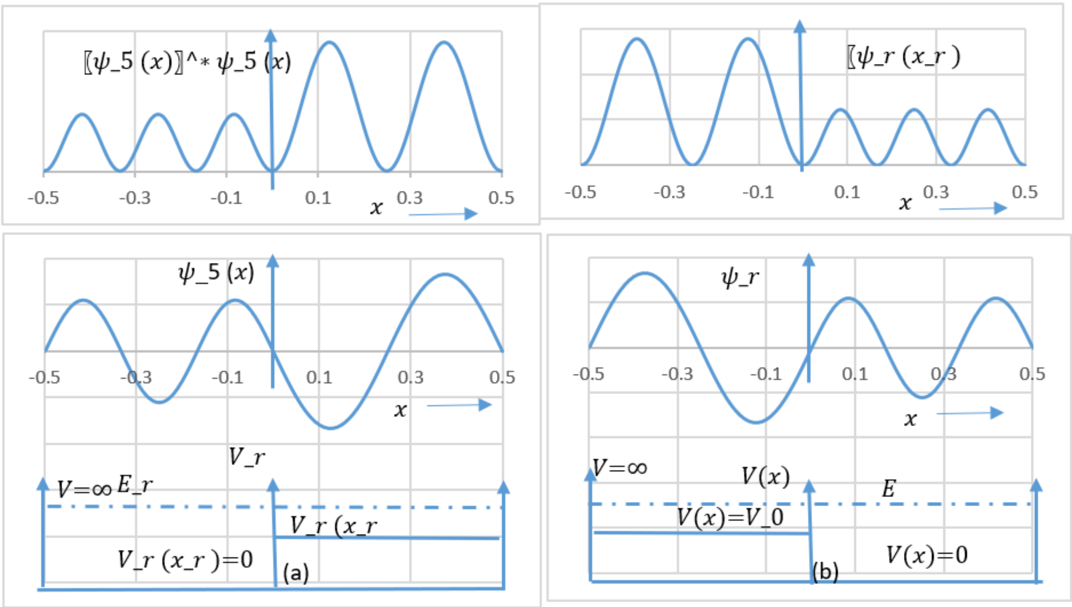


Figure 4: a) Plot of the wave function and probability density of the particle incident on a step-up potential inside an infinite square well having energy greater than the potential. b) Plot of the wave function and probability density of the particle incident on a step down potential having energy greater than the potential.

Figure 4a shows the solution of the Schrödinger equation for the bound state $n = 5$ having reduced energy eigenvalue $E_r = 178.5$. When the particle is incident on the step up potential, the impulse experienced by the particle because of retarding force, $F = -dV/dx$, at the point $x = 0$, will slow the particle as it enters in the region $x > 0$. Slowing of the particle can be verified by looking at the plot shown in Figure 3a, where the frequency of the wavefunction decreases in the region $x > 0$ and hence the kinetic energy of the particle also decreases. Even though its kinetic energy decreases in the region $x > 0$, its total energy must remain constant. The amplitude of the wavefunction increases in the region $x > 0$ because the kinetic energy of the particle is less and the particle spends more time in this region.

The energy of the particle can be varied and its reflection and transmission coefficient can be calculated by entering the following formulae in the excel file:

$$R = \left(\frac{k_1 - k_2}{k_1 + k_2}\right)^2 \quad ; \quad T = \frac{4k_1k_2}{(k_1 + k_2)^2} \qquad \text{for} \quad E > V_0$$

Where, the reduced wave number $k_1 = \sqrt{E}$, and $k_2 = \sqrt{E - V_0}$.

As the energy of the particle increases, it can be seen that the reflection coefficient decreases and transmission coefficient increases. For example, when the reduced energy was increased from $E_r = 134.7$ to $E_r = 178.5$ the reflection coefficient reduced from $R = 10.7$ % to $R = 4.1\%$. By evaluating R and T we can show that $R + T = 1$. A common misconception among students is that the reflection coefficient at the step-down potential is zero or is less than that of the step up potential (Wittmann, Morgan, & Bao, 2005). It can be verified that by interchanging the reduced wavenumbers k_1 and k_2 do not affect the reflection and transmission coefficient, i.e. R and T values are the same regardless of particle incident on a step up potential or step down potential. Hence, the reflection is not because the potential, $V(x)$, becomes larger in the direction of incidence of particle nor is it because of particles having a range of energies, but is due to the discontinuous change in potential at the point $x = 0$. A point to note here is that, the probability density in the region $x > 0$ should be a constant for a transmitted particle which does not undergo reflection but as this step potential is inside an infinite well and there is a reflection from the boundary at the point $x_r = 0.5$, the combination of incident and reflected wave will form a standing wave, as shown in Figure 4a.

Case 2: Energy less than the potential, $E < V_0$

In the case where the energy of the particle in the box is less than the potential, $E < V_0$ and particle is incident on the step up potential. Figure 5 shows the graphical representation of the probability density which is obtained by solving the Schrödinger equation for $V_r = 300$ and $E_r = 263$. Although the probability density in the region $x > 0$ exponentially decreases, it can be seen in the Figure 4 that there is a finite probability of finding the particle in the classically forbidden region $x > 0$. By changing the value of energy, one can observe the variation of the penetration distance with energy. The dependence of

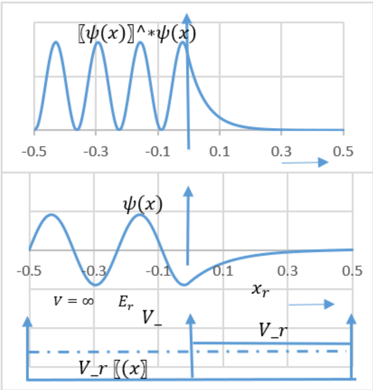


Figure 5: Plot of the wave function and probability density of the particle incident on a step-up potential inside an infinite square well having energy less than thepotential.

penetration distance on the energy is given by the following relation (Eisberg & Resnick, 2014), $\Delta x = \frac{\hbar}{\sqrt{2m(V_0 - E)}}$. To understand the effect of energy on penetration distance, one can calculate and compare the reduced penetration distance, shown in Figure 5, for two different values of energy, with the calculated value, $\Delta x_r = 1/\sqrt{V_r - E_r}$.

Sloping potential inside an infinite square well:

Consider a sloping potential inside the infinite square well given by,

$$V = \begin{cases} \alpha x & 0 < x < a \\ \infty & x \leq 0 \text{ and } x \geq a \end{cases}$$

Where α is a positive constant having units of J/m.The dimensionless reduced energy, E_r, reduced x coordinate x_r and reduced normalized wave function calculated for this case are given by,

$$E_r = \frac{E}{(m^{-1/3}\hbar^{2/3}\alpha^{2/3})}, \quad x_r = \frac{x}{(m^{-1/3}\hbar^{2/3}\alpha^{-1/3})} \text{and } \psi_r = \psi\,(m^{-1/6}\hbar^{2/6}\alpha^{-1/6})$$

Using all the above reduced variables in the Schrödinger equation we get,

$$\frac{d^2\psi_r}{dr^2} = (2x_r - 2E_r)\psi_r = G_r\psi_r$$

Where, $G_r = 2x_r - 2E_r$.

Consider the case where the energy of the particle is greater than the maximum potential energy. The Schrödinger equation was solved for the potential described above and the Figure 6a shows the plot of the probability density for the bound state $n = 9$ having reduced energy$E_r = 10.375$. As the energy of the particle is greater than the potential in the region $0 < x_r < 10$ the solution is represented as standing waves. In the region $0 < x_r < 10$ the deBroglie wavelength is longer in the region of higher potential energy as the kinetic energy of the particle decreases with increasing value of x_r. Also, as shown in the Figure 6a, the amplitude of the wave functions and hence the probability density increases with increasing value of x_r. This is because of the decrease in kinetic energy of the particle due to the increase of potential energy for increasing value of x_r. The decrease of particle velocity implies the particle will spend more time in that region and there should be an increase in the probability density.

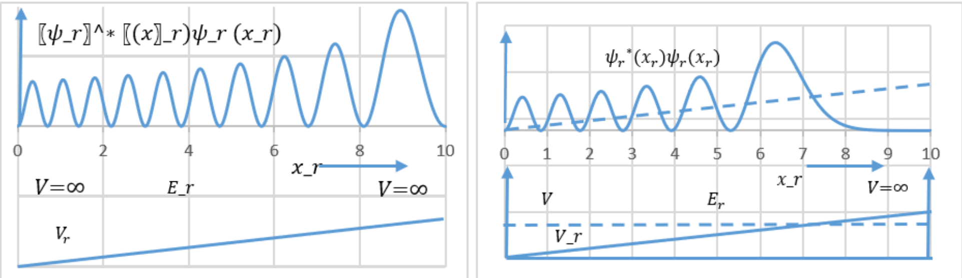


Figure 6: a) The bottom figure describes the shape of the sloping potential in an infinite potential well and the top part of the figure is a plot of the probability density when the energy of the particle is greater than the potential. The amplitude of the wave function and hence the probability density increases with increasing value ofx_r. b) The top part of the figure is a plot of the probability density when the energy of the particle is less than the maximum value of the potential energy.

Figure 6b shows the solution of the Schrödinger equation for the case where the energy of the particle is less than the maximum potential energy. The solution is represented as oscillating wave function till the point where the total energy of the particle equals the potential energy and beyond that, the wave function exponentially decreases and penetration can be observed in the classically excluded region. These problems will help students develop a qualitative understanding of the relationship between the wavelength to potential and amplitude to potential.

Summary

In this paper, we have used Numerov method and spreadsheet to solve the time independent Schrödinger equation for different cases. This paper mentions how the understanding of the shape of the wavefunction and probability density can be improved by solving the Schrödinger equation using the Excel spreadsheet for different potentials like the Infinite well with a cosine bump, one dimensional step potential, and sloping potential. We believe that students working with these cases as part of their laboratory experiments or assignments will develop further conceptual understanding of Quantum Mechanics.

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EFFECT OF AN ONLINE SCHEMA BASED LEARNING COURSE ON CONCEPTUAL UNDERSTANDING OF PHYSICS PROBLEMS

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The present study used an online module with the schema based instruction technique for teaching solving of physics problems in a systematic way. The effect of this online module was compared with an offline module using schema based instruction and a control group with drill type instruction. The study revealed that the online schema based learning course increased the problem solving ability and conceptual understanding of problems of higher secondary school students in physics when compared to the usual drill method of teaching problem solving. The study also suggests that problem solving ability does not guarantee conceptual understanding of problems. By drill method one may instil the skill of problem solving in students, but this may not guarantee conceptual understanding of problems.

Introduction

A common feel among physics teachers is that one who is good at solving problems, has understood physics well. However, a study at Harvard University (Panitz, 1998) tells us that most of the students who faired excellently well in solving physics problems did not understand the problem conceptually well.

Story problems (or word problems) are the most commonly found problems in college level textbooks that often use trivial story contexts. Such problems are well structured and are solved by applying a formula upon the data values given in the problem statement. Students usually approach such problems by sniffing into the problem text for data sets that would fit into a readymade formula ignoring the situational or structural properties of the problem. Unfortunately, most of the students solve problems in physics by memorizing equations and standardized problem solving procedures without caring for the conceptual structure of the problems.

Traditional class room learning experiences may not improve the problem solving ability of learners to a great extent (Praveen, 2007). Providing support to learners is of utmost importance for helping them develop problem-solving skills (van Merriënboer, 2013). Problem solving learning environments (PSLEs) are about engaging and supporting students in learning how to solve problems (Jonassen, 2011). Problem-solving learning environments assume that learners must engage with problems and attempt to construct schemas of problems, learn about their complexity, and mentally wrestle with alternative solutions. Such an environment would take into consideration not only calculation accuracy but also the comprehension of textual information, the capacity i) to visualize the data, ii) to recognize the semantic structure of the problem, iii) to sequence their solution activities correctly, and the capacity and willingness to evaluate the procedure that they used to solve the problem (Lucangelli et al, 1998).

In cognitive and educational psychology, schema-based learning is grounded in capturing and using expert generated schemas as frameworks for teaching and learning. Schemas can be learned to promote the acquisition of new scientific knowledge and skills. Schema based learning is a generalization and abstraction method designed to extract and condense as much information as possible from a single example of successful task completion or problem solving (Lee & Seel, 2012).

Schema-based problem solving requires use of specific schemas or templates to recognize, understand, and solve problems. Broadly, such schemas have four characteristics: they are organized so that an individual can quickly identify new instances that are similar to those on which the schema was founded; they are general templates but also have links to specific individual experiences that match the current template; they guide an individual's efforts to draw inferences, make estimates, and create plans to solve problems; and they connect with essential skills or procedures the individual already has (Marshall, 2012).

Earlier research (Jonassen 2011; Jitendra et al, 2015; Fuchs et al, 2004) clearly suggests that schema based learning improves problem solving ability of learners.

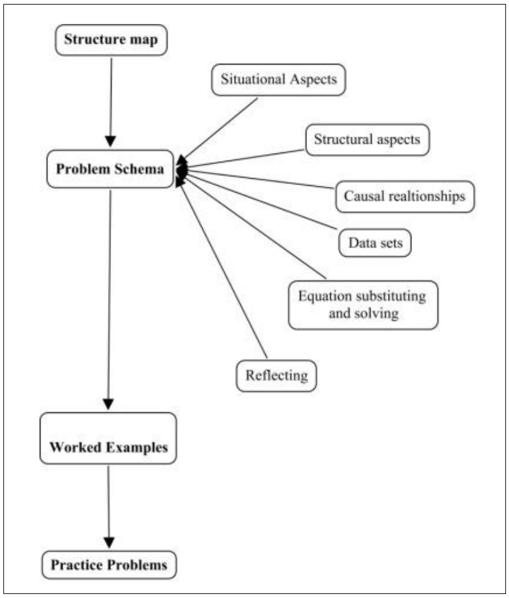

Figure 1: Framework of a story problem solving learning environment

The present study tries to find the effect of schema based learning on the problem solving ability of higher secondary school students in learning physics. Also it tries to find out if problem solving learning environment associated with schema based learning will produce the same effect if presented on a Moodle based virtual learning environment, because courses mounted on Moodle platform has a greater reach and could teach the new method of problem solving without giving training to teachers themselves. This software which offer practice in story problems will serve as a complimentary instructional material to the theory classes that are taken in the formal classroom hours. Thus, a major difficulty of teaching problem solving can be successfully dealt by leaving the task to the students themselves. Students will have to engage with the schema based instructional module available online through their computers either in the school or in their home environment, experiencing a self paced and self instructional way of learning. The research questions that guided this study were the following:

1. Will schema based problem solving module on Moodle produce significant increase in conceptual understanding of problems in physics of higher secondary level students?
2. How will the instructional strategy and problem solving ability effect upon conceptual understanding of problems in physics of higher secondary level students?

Method

The sample for the present study comprised of 113 students of grade 11 from three schools of Kozhikode city in Kerala. The present study is a quasi-experimental one and the design applied here is pre/post-test non-equivalent groups design. The three groups were statistically equated using logical mathematical intelligence and nonverbal intelligence as covariates. The effects of the schema based instruction on conceptual understanding of problems and the problem solving ability were examined using ANCOVA. The design of the study is summarised in the Table 1. It shows the interventions made on the control group as well as the experimental groups at the different stages of the study.

Stage	**Experimental group 1 (Sample size =33)**	**Experimental group 2 (Sample size =49)**	**Control group (Sample size =31)**
Pre - testing	Measurement of 1. Non-verbal intelligence 2. Logical-mathematical intelligence 3. Problem solving ability	Measurement of 1.non-verbal intelligence 2.logical-mathematical intelligence 3.problem solving ability	Measurement of 1. Non-verbal intelligence 2. Logical-mathematical intelligence 3. Problem solving ability
Treatment	Teaching problem solving through schema based instruction module with “Moodle” (10 hours of face to face teaching of theory + About 5 hours of online engagement for problem solving)	Teaching problem solving through schema based instruction without the “Moodle” (8 hours of face to face teaching of theory + About 4 hours of engagement for problem solving)	Teaching problem solving in drill method (10 hours of face to face teaching of theory + About 3 hours of engagement for problem solving)
Post-testing	Measurement of 1. Problem solving ability 2. Conceptual understanding of problems	Measurement of 1. Problem solving ability 2. Conceptual understanding of problems	Measurement of 1. Problem solving ability 2. Conceptual understanding of problems

Table 1: Design of the study

The tools used for the study were:

No.	Test	Reliability
1	Raven's standard progressive matrices to measure non verbal intelligence of the students.	The reliability coefficients as reported by Raven vary from 0.80 to 0.90
2	Logical-mathematical intelligence constructed and standardized by Praveen & Vijesh (2016)	Test-retest reliability 0.74 (N=31)
3	Problem solving ability test in physics constructed and standardized by Praveen (2016)	Cronbach Alpha method (0.78)
4	Test of conceptual understanding of problems in physics constructed and standardized by Praveen (2016)	Cronbach alpha method (0.91)

To conduct this study, a teaching module for story problem learning environment was framed as a sequence of progressive chunks through which the learner is escorted with proper cognitive scaffolds. This included 5 steps (Praveen, 2016):

STEP I Identify the problem type

STEP II Identify the problem schema

STEP III Imagine and draw the situation.

STEP IV With situation in mind, superimpose data on problem schema.

STEP V Substitute, Calculate and Reflect.

In experimental group 1, students were taught the theory of one dimensional motion (using the expository method of teaching) during the usual class hours in the face to face mode and the problems were asked to be done as home work in the virtual learning environment on the Moodle platform (using schema based learning). This software gave the necessary instructions towards introducing schema based learning, the necessary conceptual background of the theory portion in physics and then did stepwise handholding of doing physics problems. Later after getting familiarized with worked examples, the software would also test them by giving practice problems in a self paced manner. The course can be accessed through a guest password (4444) available at http://courses.prama.org.in/login/index.php

In the experimental group 2, the theory portion was taught in the usual expository method of teaching and the problems were dealt in the schema based method of instruction but without Moodle (using the chalk and talk method).

In the control group, the theory portion was taught using the expository method of teaching and the problems were dealt in the usual drill method by a regular teacher in the school.

The same set of problems was given to the experimental groups and control group for practice and homework. The difference between the post-test and the pre-test (the gain score) was taken as a measure of the problem solving ability. The post test scores were taken as measure of conceptual understanding of problem.

Results

Effect of the Moodle based instructional module on the conceptual understanding of problems was examined using one way ANCOVA. Further to examine the main effects and interaction effect of instructional strategy and conceptual understanding of problem, on problem solving ability, again a two way analysis of variance was performed with 3X2 factorial design.

Effect of instructional strategy on conceptual understanding of problems

One way ANCOVA was performed to determine if a statistically different significance existed between schemas based instruction using Moodle, Schema based instruction without Moodle and drill method of instruction on the conceptual understanding of problems controlling for nonverbal intelligence and logical-mathematical intelligence. The variables nonverbal intelligence and logical-mathematical intelligence were controlled as the investigator felt that these were the major confounding variables that would affect the dependent variable of this study.

Estimates				
Dependent variable: Conceptual understanding				
Study group	**Mean**	**Std. error**	**Confidence interval (95%)**	
			Lower bound	**Upper bound**
Expt. Group 1(Schema based instruction using Moodle)	39.58[a]	1.54	36.53	42.64
Expt. Group 2 (Schema based instruction without Moodle)	36.12[a]	1.24	33.67	38.58
Control Group (Drill method of instruction)	32.19[a]	1.52	29.17	35.22
a. Covariates appearing in the model are evaluated at the following values: Non-Verbal Intelligence = 46.85, Logical mathematical Intelligence = 18.41.				

There was a significant difference in conceptual understanding of problems [F (2,105) = 6.010, p =.003] between the instructional strategies. The partial eta squared value indicates the effect size is small (0.103). Post hoc tests showed there was a significant difference between instructional strategy using schema based instruction on Moodle and drill method of teaching (p = 0.002). Comparing the estimated marginal means showed that the most gain of conceptual understanding of problems was achieved on schema based instruction using Moodle (mean = 39.58 scores) compared to instructional strategies with schema based instruction without Moodle and drill method of teaching (mean = 36.12 scores, 32.19 scores respectively). Thus, we conclude that the instructional strategy using schema based instruction on Moodle is effective in fostering conceptual understanding of problems than the drill method in the teaching of problem solving.

Effect of conceptual understanding of problems on problem solving ability

A two way ANOVA was performed to find out the main effects and interaction effects of instructional strategy and conceptual understanding of problems on the gain in problem solving ability. The main effect of instructional strategy is significant, $F(2,104) = 12.009$, $p < .000$.

Post hoc tests showed there was a significant difference between instructional strategy using schema based instruction on Moodle and drill method of teaching ($p = 0.000$). Also there was a significant difference between instructional strategy using schema based instruction without Moodle and drill method of teaching ($p = 0.007$). The estimated marginal means showed that the most gain of problem solving ability was achieved on schema based instruction using Moodle (mean=12.50 scores). The estimated marginal means for the other instructional strategies, using schema based instruction without Moodle and drill method of teaching were 10.45 scores and 7.09 scores respectively.

The main effect of conceptual understanding of problems on problem solving ability was not significant, $F(1,104) = 1.097$, $p > .050$. This means that problem solving ability does not guarantee conceptual understanding of problems. The interaction effect of instructional strategy with conceptual understanding of problems was significant, $F(2,104) = 3.199$, $p < .050$. To interpret the interaction, the task is made easier by graphing the instructional strategy with conceptual understanding of problems estimated marginal means as shown in Figure 2.

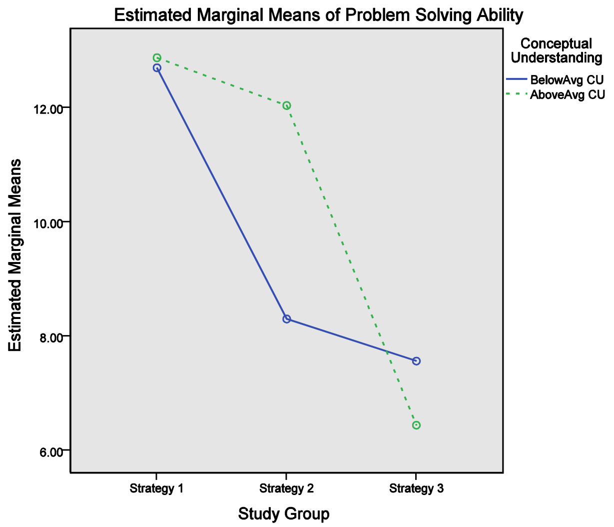

Figure 2: Estimated marginal means of the interaction- instructional strategy with conceptual understanding of problems

We see that the mean of problem solving ability is higher for the above average conceptual understanding group even if you teach them either through strategy 1 (schema based instruction with

Moodle) or strategy 2 (schema based instruction with Moodle). But if you teach with strategy 3 (drill method), we find some of the below average students gain a problem solving ability higher than the students in above average conceptual understanding group. To put it differently some students of the above average conceptual understanding group may have low gain in problem solving ability if taught with drill method.

Conclusion

We realize that for teaching problem solving, schema based learning with Moodle increases the conceptual understanding of problems and problem solving ability of higher secondary school students in physics when compared to the usual drill method of teaching. This finding is in line with the research studies of Powell (2011), and Jitendra et al (2013, 2016) that suggest that schema based instruction develops skill of solving word problems. This study also follows the studies of Triyanto et al (2016) and Lin (2011) which suggests that Moodle enhances critical thinking and problem solving skills of learners. As schema based instruction uses concept map like structures, the study endorses work by Moore (2013) that suggest concept maps as advance organizers or navigation aids for hypermedia documents promote conceptual understanding. Again, schema based problem solving which rely on mathematical modelling will enhance problem solving ability and conceptual understanding of learners is in line with the study of Schuchardt & Schunn (2016) where students given modelled process instruction improved in their ability to solve complex mathematical problems.

The present study suggests the use of schema based instructional modules for teaching problem solving to foster conceptual understanding of problems. By drill method one may instil the skill of problem solving in students, but this may not guarantee conceptual understanding of problems. If a story problem solving environment could be prepared by expert teachers using the elements of schema based learning and if this is hoisted on an online learning environment such as Moodle, it could benefit the students to gain expertise in solving story problems in a non-threatening and homely environment. Also this will take away the burden of an ordinary higher secondary school teacher who struggles to complete the theory portion in time and finds it difficult to devote quality time to teach solving of story problems in physics.

Acknowledgement

The investigator places on record, gratitude to the UGC of India for the UGC research award scholarship endowed towards this post doctoral research project.

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UNDERSTANDING INERTIA OF MOTION THROUGH GALILEO'S INCLINED PLANE EXPERIMENT

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In our experiences of daily life, we come across several objects at rest but we don't come across bodies moving with uniform velocity over very long intervals of time. Hence, inertia of motion is more difficult to comprehend than inertia of rest. Two activities were designed to help high school students understand that inertia of uniform motion of a body is possible in the absence of net force acting on it. In the first activity, a linear air track was used to make students understand that removal of friction allows a body to maintain its velocity. In the second activity, Galileo's inclined plane experiment was used to help students visualise that as the opposing forces reduce, a body tends to travel longer distances. Extrapolating this observation leads to a conclusion that a body would travel forever with uniform velocity on a horizontal frictionless surface. Inclined planes with different inclinations were designed, fabricated and deployed in the study. A random set of students studying in 8th and 9th grade was chosen for the study. A pre-test and a post-test were administered to this set. The results showed a significant impact in the students' understanding of the concept.

Introduction

Children always have a propensity to observe nature, formulate own opinions based on their repeated observations. Their perceptions lead them to make intuitive conclusions and construct beliefs about how things work. Sometimes, these intuitive conclusions may be consistent with scientific observations and sometimes may not be.

Moving things always fascinate children. They come up with their own mental models to explain why things move. Most children carry a preconception that a moving object is always associated with a force (Clement, 1982). Some of the common misconceptions in children (and sometimes even elders) in understanding motion has been studied by Gunstone and Watts (1985), Rosalind Driver et al (1985) and Roger Osborne (1985). While the state of rest is generally perceived as a consequence of no force and is considered intrinsic to a body, the state of uniform motion is perceived to be always associated with a force (Clement, 1982).

The question of "what causes motion?" arouses curiosity in children. To find an answer to this question, children have to understand the concept of inertia. Children are taught, with some examples, about inertia of motion at school level, which include the following: a person standing in a moving bus falls forward when the bus is suddenly stopped; a ball placed on a moving wagon moves forward when the wagon is stopped suddenly; and so on. But these examples are not adequate to visualise the state of inertia of motion. Uniform motion is something that cannot be easily observed or experienced on the Earth. However, understanding uniform motion is extremely important since it is also the intrinsic nature of a body.

This work focuses on understanding inertia of motion through an experiment attributed to Galileo. Galileo's inclined plane experiment is a great tool to understand the inertia of motion. This work was intended to study the impact of experimental approach to understand uniform motion.

Galileo's thought experiment

Galileo did not appreciate the idea proposed by Aristotle that a ball rolling would come to rest because it desires to be in its natural state, namely the state of rest, and a force is necessary to keep it in motion. Using the inclined plane experiment, Galileo was able to explain that Aristotle's idea was wrong (Drake, 1973). He proposed that if two inclined planes with equal slope were placed opposite to each other, then a ball rolling down one of the slopes would move up the other slope tending to acquire the same height as on the first inclined plane if the surfaces were made smoother and smoother. He extended the idea that if the slope of the second plane were reduced, the ball would travel a longer distance on it to move up closer to the same height as on the first inclined plane. He extended his argument that if the planes were made ideally smooth and the second plane were to be made horizontal, the ball would move forever with uniform velocity.

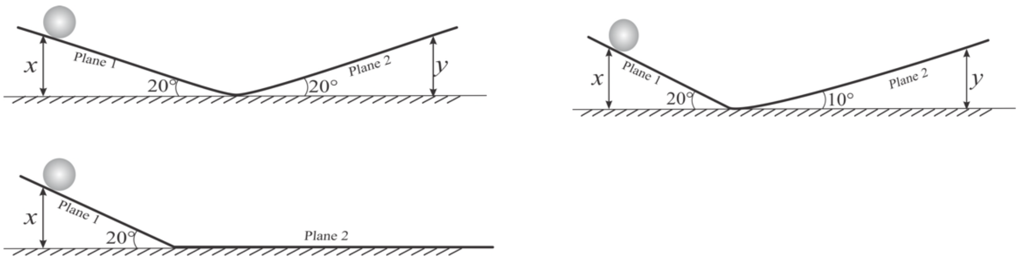

Figure 1: Galileo's inclined plane experiment–schematic representation.

Design of the experiment

Galileo's inclined plane experiment would work perfectly under ideal conditions. But practically it is limited by factors like friction, accuracy in bending and creating a near ideal channel for a ball to roll. In this design, the first challenge was to choose an appropriate material which offers minimum rolling friction. Stainless steel was found to suit the requirements. Stainless steel pipes were joined to create a channel on which a stainless-steel ball would roll. The experimental setup also required inclined planes with different angles. Five different inclined plane setups were fabricated with included angles of 140°, 145°, 150°, 155° and 160°. In all these setups, the angle of inclination of the first plane was fixed at 20° with respect to the horizontal. The corresponding angles of inclination of the second plane were fixed at 20°, 15°, 10°, 5° and 0° with respect to the horizontal. The setups were fixed to a wall precisely.

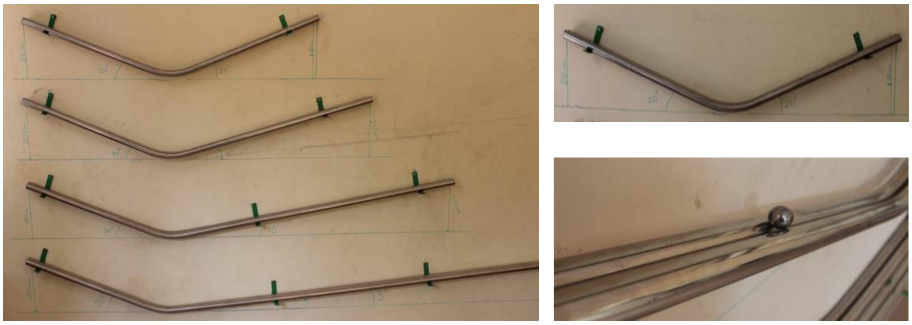

Figure 2: Galileo's inclined plane experimental setup

Methodology

While several approaches such as Predict–Observe–Explain (POE) (White & Gunstone, 1992), Interactive Conceptual Instruction (ICI) (Savinainen & Scott, 2002), Investigative Science Learning Environment (ISLE) (Etkina & Van Heuvelen, 2007) are generally used for activity based learning, the POE approach was adopted, since it works best with activities that allow immediate observations and interpretations.

A set of 29 students of grade 8 and a set of 40 students grade 9, studying in English medium, were chosen for the study. The chosen students were already introduced to the basic concepts of kinematics and forces in their school curriculum. The students were administered a pre-test, followed by two activities and then a post-test. Content validation of the questions used in the pre-test and post-test were done by subject experts.

Pre-test

The pre-test consisted of 11 questions, out of which the first five were to find out if the students had a basic perception of states of motion of moving bodies that they come across in different real life situations. The next three questions were motion diagram questions, in which the students were asked to identify uniform and accelerated motions. The last three questions tested the students' understanding of conditions under which a body can be at rest or in uniform motion. The last three questions were also included in the post-test. Except for one, all the questions were of multiple choice type.

About 90% of the students had the basic understanding of uniform and accelerated motions. However, majority of students could not answer the last three questions (given in table 2) correctly.

General perception of students was to associate motion with force. Most of the students expressed that a force should be acting continuously on an object to keep it in motion. When asked about state of rest, some students had a preconception that a force is necessary to keep an object at rest. Some of them even said that friction is necessary to keep an object at rest.

Activities were designed for better understanding of the concepts of rest and uniform motion and thus the concept of inertia.

Activity 1: Frictionless surface using linear air track

Several authors (Pendrill et al, 2014) have developed activities to investigate the role of friction on motion. However, the idea of motion under frictionless conditions has not been addressed adequately. Hence, it is necessary to induce an idea of frictionless surface with appropriate activities.

There was a demonstration conducted to help children visualise motion in the absence of friction. The activity consisted of two parts and was demonstrated using a linear air track setup on which a slider moved. In the first part, there was no air cushion established between the slider and the track. The slider was given an initial velocity using a spring-loaded mechanism. Students were made to observe how far the slider travelled. In the second part, the friction between the slider and the track was reduced considerably by establishing an air cushion between the slider and the track. Initially, students were made to predict how far the slider would travel. Most of them said that it would travel a little more distance than in the first part and very few said that the slider would travel for a much longer distance. The slider was given the same initial velocity as in the first part. Students were made to observe how far the slider travelled. Students could observe the difference in the distances covered by the slider during the two parts of the activity. This activity helped students visualise motion of a body in a nearly frictionless situation. They discovered that an object could travel a much longer distance for the same initial velocity.

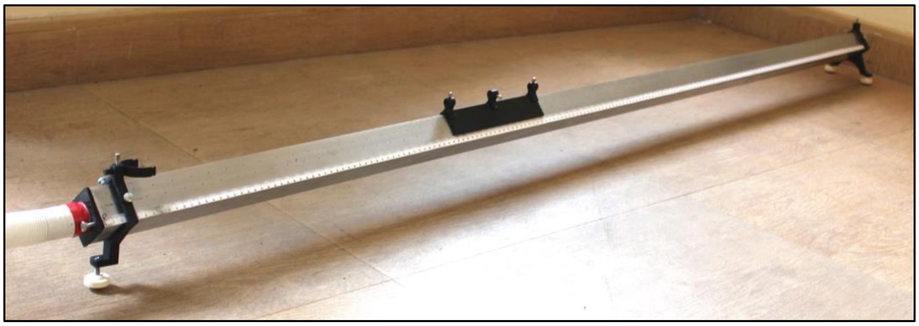

Figure 3: Linear air track

Activity 2: Galileo's inclined plane experiment

Students were introduced to Galileo's inclined plane experiment to observe accelerated and decelerated motions on inclined planes and discover a pattern of accelerated and decelerated motion through a series of observations. They were made to perform the experiment by allowing a ball to roll down from a height (h), with respect to a horizontal reference, on the first plane and observe the following: distance travelled by the ball on the first plane and the second plane; height achieved by the ball on the second plane. The experiment was repeated for five different cases (see Table 1). The students recorded their observations in the following table.

Case	Angle of plane 1	Angle of plane 2	Distance travelled on plane 1	Distance travelled on plane 2	Does the ball approximately reach the same height on both planes? (Yes/No)
Case 1	20°	20°			
Case 2	20°	15°			
Case 3	20°	10°			
Case 4	20°	5°			
Case 5	20°	0°			

Table 1: Observation table, Galileo's inclined plane experiment

To check the students' observation and interpretation, six questions were asked out of which three were based on observation and the other three were based on interpretation. In the first three questions, the students were asked to comment on the distance travelled by the ball on the second plane in each case and the corresponding heights attained by the ball on the second plane. In the next three questions, they were led to interpret the kind of motion the ball can have on a horizontal plane, in the presence of friction and in the absence of friction.

After performing the activities 1 and 2, it appears from the answers that most students had understood that uniform motion is possible in the absence of forces responsible for deceleration. In activity 1, substantial reduction of friction occurred due to air cushion and in activity 2, the effect of gravity was reduced by decreasing the inclination. Students were able to consolidate the observations from the two activities and could extrapolate that a moving body would continue to move on a horizontal frictionless plane with uniform velocity. Students were then introduced to the term inertia and were made to understand the definition of inertia based on their observations and conclusions. They were then posed with questions like "is the state of rest of an object similar to state of uniform motion?", "is state of uniform motion of a body as natural or as basic or as intrinsic as state of rest?". Students were able to convey their thoughts as "since net force is zero in both the cases, they should be similar"; some said "they are equivalent"; and some opined that "both rest and uniform motion are natural to a body and no net force is required to keep them in those states".

Post-test

The post-test consisted of five questions. The first question was an extension of the three questions asked in the pre-test relating to uniform and accelerated motions. The students were asked to associate state of inertia and hence net force acting on the body, to different kinds of motion.

The next three questions are identical to those asked in the pre-test and these questions are as follows:

2. A body is at rest only when (a) there is a continuous net force acting on it

(b) there is sufficient friction

(c) there is zero net force acting on it.

3. A body moves with uniform velocity only when

(a) there is a continuous net force in the direction of motion

(b) there is zero net force on the body

(c) there is a continuous net force opposite to the direction of motion.

4. Can a moving object keep moving forever or does it always seek a position of rest?

Table 2: Post-test questions

In order to test the ability of students to apply the concept of inertia in a new situation, a question from the article *"Student preconception in introductory mechanics"* (Clement, 1982), was included. The question is given in the following table.

5. A rocket is moving in outer space with engines off from point A to point B. There is no external force on that object. The engine is turned on at point B until the rocket reaches point C and then turned off again. In which direction will the rocket travel after point C? (Choose the correct representation from the following.) (Clement, 1982). Give reason to justify your choice.

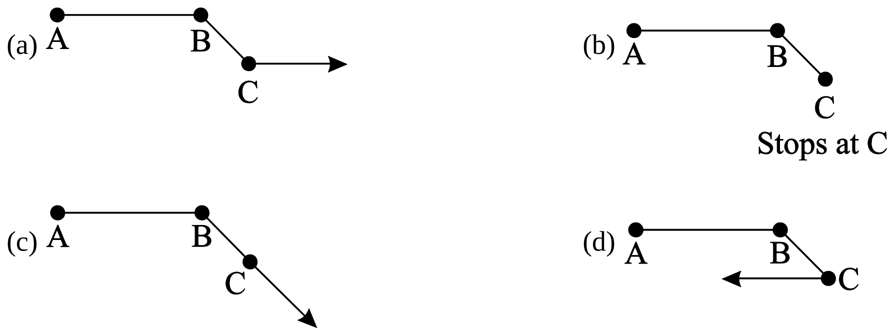

Table 3: Post-test question

Results

Question 1: About 90% of students identified correctly the states of motion in the pre-test. After the post-test, about 60% of those were able to associate the state of uniform motion to inertia.

Question 2: About 72% of the students had answered correctly in the pre-test while 89% answered correctly in the post-test.

Question 3: Only 3% of the students had answered correctly in the pre-test while about 42% answered correctly in the post-test.

Question 4: About 3% of the students had answered with clarity in the pre-test and rest of the answers were not clear. In the post-test 71% of the students could answer this question (a written response question) with clarity.

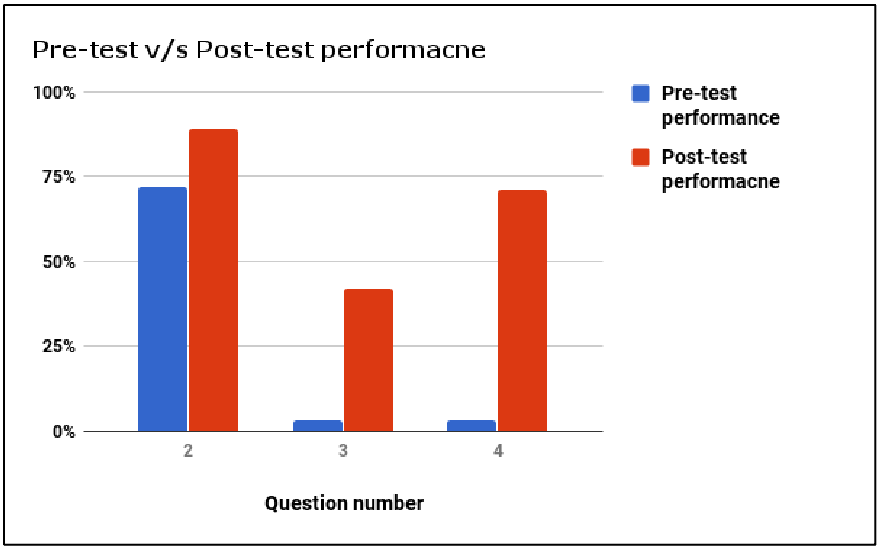

Figure 4: Comparison of students' responses to the questions in pre-test and post-test

Question 5: About 50% of students answered this question correctly. While the students' understanding of inertia of motion seems to have improved with the help of experiments, efforts are on to verify the same for larger sample size.

Conclusions

The response of students in the pre-test and the post-test lead to the following conclusions.

1. On analysing the response of the students in the pre-test, it is evident that the concepts of uniform and accelerated motion were clear to the students. However, the concepts of inertia of rest and inertia of uniform motion were not clear before the experiment.
2. Many students had a preconceived notion that "friction is essential for a body to be at rest". Post experiment, most of the students were able to overcome this misconception.
3. The concept of inertia of motion seemed to have become clear to students after performing the experiments. This is evident from the percentage of students answering questions 3 and 4 correctly in the post-test.
4. The response of students for question 5 reinforces the takeaways from the responses to the questions 1, 2, 3 and 4.

It is thus clear that the activities performed lead to understanding of the concept - "inertia of uniform motion implies a zero-net force condition". These activities are very different from classical examples used to teach the concept of inertia. Moreover, an experiment or an activity gives hands on experience to students and is hence a powerful tool for learning.

Further studies are being made by the authors to bring out clearly the equivalence of the state of rest and of uniform motion, which forms the basis for Galilean transformations.

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HOT SKILLS ANALYSIS IN STATE BOARD HIGHER SECONDARY PHYSICS EXAMINATIONS OF INDIA

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The global higher secondary physics teaching has ultimate goal to inculcate & augment higher order thinking (HOT) ubiquitously. The present study concerns analysis of Indian state board higher secondary physics examination questions, for HOT skills. The researchers utilized content analysis followed by peer review methods to analyze & categorize 12 Indian state board physics examination questions in to taxonomy table and questions weighted into different cognitive processes utilizing Krathwohls' revised Blooms taxonomy. The analysis revealed domination of lower knowledge domains and lower order thinking (LOT) skills and negligence of HOT skills in assessment questions among almost all state board physics examination papers.

Introduction

Once, John Dewey asked a class, "What would you find if you dug a hole in the Earth?" The class did not respond, so Dewey posed the query another time, again receiving no response. The class teacher chided Dewey, saying, "You're asking the wrong question." Turning to the class, she said, "What is the state of the center of the Earth?" The class replied in unison, "igneous fusion (McDavitt, 1994; Bloom et al, 1956). This wasn't the illustration of an old American classroom alone, its' still true worldwide and elemental among large number of Indian science classrooms. Although the primary aim of higher secondary science education in India is to develop objectivity, critical thinking, problem solving, decision making, application in varied novel situations and creativity (Secondary Education Commission (1952-53), National Policy on Education (1986), National Focus Group Position Paper (2006)). Which in a nutshell defines higher order thinking (HOT) skills, (McDavitt 1994), that basically means thinking with higher levels of cognitive processing (Ramos, 2013). But it is universally believed that classroom physics teaching-learning is very much rote memorization (Halloun, 1985, Elby, 1999; Bergin, 2015), lacking and in need to enhance HOT skills in physics classrooms (McLoughlin & Hollingworth, 2003; Constantinous, 2004). As only a minority of teachers view fostering HOT skills as important objective of teaching physics (Barak & Shakman, 2008).

Although altogether planning, teaching and assessment stages are used to achieve these HOT skills educational aims, assessment is a crucial stage and an essential component of effective instruction (Jones et al, 2009)). It, not only test the students' overall cognitive levels, (Omar et al, 2012), that makes judgments and decisions about the effectiveness of students and teachers, (Rosenshine, 1971), but also forms the basis of what teachers teach for and what/why students study for. As students' epistemological beliefs aren't much to understand physics, they are more to pass examinations, to score high and to get good grades (Elby, 1999). Examination patterns very much determine the path teachers and students choose. The examinations having lower order question, that are less complex focusing on recall and memory only force students to study and prepare through memorization without utilizing HOT skills regardless of their mental abilities.

HOT questions whereas, encourage students to think deeply about the subject matter (Barnett & Francis, 2012). Examinations with effective questions help raise issues that require students to think (Black et al, 2003), including problem solving questions (Leeds, 2000) and significantly more complex thinking questions stimulate a student's mental activities (Chin & Langsford, 2004). The art of skilful questioning is a key to productive discussion by engaging students in HOT skills (Chin & Langsford, 2004). The quality of asked questions on exams contributes developing creativeness of students and their criticism ability (Azar, 2005).

However, central board of secondary education (CBSE) India has made set criteria for HOT skills question percentage in its examination papers (CBSE question papers), but no such provisions are available in state boards. Where, India being big populous country having 29 states, every year a large number of students enrolls for state boards higher secondary examinations. The present study analyzes these Indian state board higher secondary physics examination questions. Also there have been a lot of researches in analysis and categorization of physics examination questions in to cognitive levels. But a scarcity of researches in Indian context calls an exigency to see what state boards are evaluating in terms of thinking skills.

However analysis and categorization of examination questions required some Taxonomy. Bloom's Taxonomy (Bloom et al, 1956), has been widely used in education fields (Chang & Chung, 2009), as a means of categorization and determining the congruence of assessments (Airasian et al, 2001), an assessment tool (Krathwohl, 2002), in constructing questions (Lister & Leaney, 2003) and a guideline in designing reasonable examination questions belonging to various cognitive levels (Omar et al, 2012). But Taxonomy is being revised by Krathwohl with a two dimensional framework extension (Krathwohl, 2002), and some other major changes. So we utilized revised Taxonomy for analysis and categorization of examinations questions into the Taxonomy table, which is explained in next section. (the references are too distracting, can we quote them as clubbed together at two places after the main text)

Methodology

Selection of question papers

Out of all 29 states we randomly selected 12 Indian state board higher secondary physics examination question papers of current year 2017 (exams held March- April 2017). Most states have more than one examination paper sets; we analyzed all the sets and found that they all have same difficulty levels. So we considered only one set from each of the 12 states (states included- Assam, Bihar, Jammu & Kashmir, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Naidu, Telangana, Uttarakhand, and Uttar Pradesh).

Assessment of questions

Assessment of all the questions papers was the utmost difficult part to do justice with. So in several meetings we did content analysis of all 12 question papers and state-wise tabulate them into Taxonomy table. After which to validate our content analysis we further send our work to 15 experts in fields of physics and physics teaching from Aligarh Muslim University Aligarh, Banaras Hindu University Varanasi, Indian Institute of Technology New Delhi, and Jamia Millia Islamia University New Delhi, to further cross check our work. The expert comments were then incorporated and we finally came up with an all in one taxonomy table given in the next section. Table1and Table 2 clearly illustrates some examples and behaviors for categorization of questions into cognitive and knowledge dimensions respectively.

The Taxonomy table as described by Krathwohl et al (2001) has two dimensions- knowledge and cognitive processes. From simplest to complex former have four subcategories -factual, conceptual, procedural and meta-cognitive, and later six subcategories -remember, understand, apply, analyze, evaluate and create. Also many questions have two or more parts and many have selection options (choice) for students. We considered that the best approach is to take each part of the question as separate question and question paper as a whole.

Cognitive category	**Example keywords**	**Example questions**
Remember	List, recall, define etc.	Define Krichhoff's law
Understand	Arrange, discuss, classify	
Apply	Sketch, illustrate, explain, solve etc.	Explain the working of p-n junction diode as full wave rectifier
Analyze	Analyze, calculate, differentiate, distinguish etc.	Differentiate between nuclear fission and fusion
Evaluate	Arrange, propose, organize etc.	What will happen if an electric dipole is subjected to an uniform electric field
Create	Judge, assess, justify etc.	

Table 1: Illustrative examples of categorization in cognitive dimension

Knowledge dimension	**Example behavior**
Factual	The basic elements students must know to be acquainted with a discipline or solve problems.
Conceptual	The interrelationships among the basic elements within a larger structure that enable them to function together.
Procedural	How to do something, methods of inquiry, and criteria for using skills, algorithms, techniques, and methods.
Meta Cognitive	Knowledge of cognition in general, as well as awareness and knowledge of one's own cognition.

Table 2: Example behavior for categorization in knowledge dimension

Analysis & Interpretations

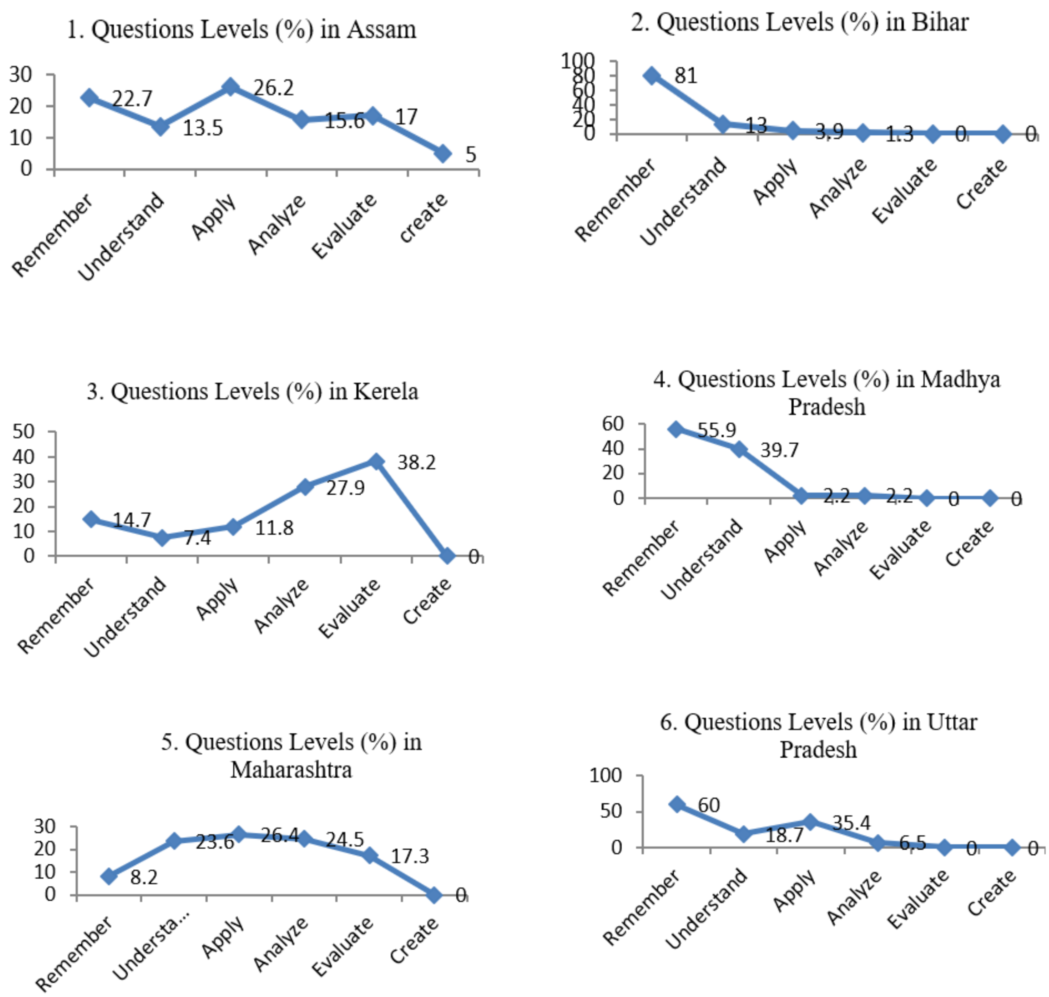
The categorization of all questions in all the question papers in to Taxonomy table is as follows:

States	Cognitive Processes Dimension						Knowledge dimension
	Create	Evaluate	Analyze	Apply	Understand	Remember	
Assam	-	-	-	-	1	-	Meta Cognition
	1	3	5	6	3	2	Procedural
	1	2	2	3	4	6	Conceptual
	-	2	1	1	-	10	Factual
Bihar	-	-	-	-	-	-	Meta Cognition
	-	-	-	1	1	3	Procedural
	-	-	-	-	4	6	Conceptual
	-	-	1	2	2	27	Factual
Jammu & Kashmir	-	-	-	-	-	-	Meta Cognition
	-	-	-	-	2	8	Procedural
	-	-	-	-	6	6	Conceptual
	-	-	1	1	5	14	Factual
Karnataka	-	-	-	-	-	-	Meta Cognition
	-	1	2	4	6	-	Procedural
	-	1	-	1	2	3	Conceptual
	-	2	4	2	3	12	Factual
Kerala	-	-	-	-	-	-	Meta Cognition
	-	4	3	3	1	1	Procedural
	-	3	3	1	2	3	Conceptual
	-	1	4	-	2	5	Factual
Madhya Pradesh	-	-	-	-	-	-	Meta Cognition
	-	-	-	-	6	4	Procedural
	-	-	-	1	8	5	Conceptual
	-	-	1	-	2	22	Factual
Maharashtra	-	-	-	1	-	-	Meta Cognition
	-	-	1	11	6	-	Procedural
	-	3	5	1	6	3	Conceptual

	-	2	5	-	1	2	Factual
Rajasthan	-	-	-	-	-	-	Meta Cognition
	-	-	-	2	4	3	Procedural
	-	1	2	-	4	3	Conceptual
	-	-	1	1	2	13	Factual
Tamil Nadu	-	-	-	-	-	-	Meta Cognition
	-	1	1	6	9	3	Procedural
	-	-	-	-	8	10	Conceptual
	-	2	-	2	4	27	Factual
Telangana	-	-	-	-	-	-	Meta Cognition
	-	1	1	2	5	-	Procedural
	-	3	1	2	-	2	Conceptual
	-	2	1	1	-	9	Factual
Uttarakhand	-	-	-	-	-	1	Meta Cognition
	-	-	2	7	-	2	Procedural
	-	1	2	3	3	3	Conceptual
	-	1	1	1	7	6	Factual
Uttar Pradesh	-	-	-	-	-	-	Meta Cognition
	-	-	-	8	2	4	Procedural
	-	-	1	-	2	5	Conceptual
	-	-	-	1	1	10	Factual

Table 3: Questions in State wise Taxonomy Table

It is evident from the taxonomy table that questions are evaluating mostly lower cognitive and knowledge levels and highest level i.e. create and meta-cognitive are hardly evaluated. There is no general trend in number of questions among these levels but some state boards have very large number of questions in *remember* and *factual* dimensions alone as respectively in Bihar (36, 32), Jammu (28, 21), Karnataka (15, 23), Madhya Pradesh (31, 25) and Tamil Nadu (40, 35). While the interpretation of questions among cognitive processes will be clearer by the following graphical representation of percent weighted questions in physics examination papers of some states.



Graphical representation of questions levels (%) weighted across examination papers

The clear representation so far found is complete absence of HOT skill *Create* in cognitive process dimension except in Assam where 5% questions weighted from *Create*. The major bulk questions are weighted LOT skills (*Remember*, *Understand*) or in some states Intermediate order thinking (IOT) skills (*Analyze*, *Apply*) while HOT skills (*Evaluate*, *Create*) are not being assessed. Regarding HOT skills only *Evaluate* get some percent weighted questions which is still very low. As asserted by Mody (2011) what we all (teachers) test is memory, memory and only memory. All we emphasize is on lowest level of intelligence… i.e. memory. The conceptual development of the subject is completely missing. This comes to be true for almost all of the state question papers under study. Among all 12 state board examination papers 8 of them have more than 50% LOT skills questions, and condition is more vulnerable for states as Bihar, Jammu & Kashmir, Madhya Pradesh and Uttar Pradesh having 0% question weighted in HOT skills (not even in *Evaluate*) and 81%, 95%, 95.6% and 78.7% LOT skills questions respectively. What are their assessment objectives is a question to be thought about. Their more focus on LOT skills questions assesses only memorization strength of the students leaving their mental capabilities and their subject conceptual understandings. And deriving students further toward rote memorization without any meta-cognitive knowledge and HOT skills proficiency. It is better to implement an assessment system based on objectives according to revised Bloom taxonomy with definite HOT skills orientation.

Educational measures

The Indian state board physics examination papers show a critical situation for their evaluation systems. Realizing the importance of HOT skills it calls a review of whole teaching learning process in state boards. Following are some of the implications:

For educational system

The biggest role is to be played by state board educational systems. They need to recognize and think over the importance of HOT skills in subjects as physics and work over it. They should review their planning, teaching and evaluation strategies to stop rote memorization and develop- enhance needed HOT skills among students. It first requires state educational systems to provide proper professional development provisions, courses and means for physics teachers and then preparing schools to develop these higher knowledge and cognitive process dimensions. The current employment needs require more creativity and generic skills with critical and higher thinking jobs. HOT skill inculcation is critical for future learning and can be very well developed by developing the evaluation systems accordingly. As early as possible state boards need to think over it.

For physics teachers

Physics teachers should themselves teach to inculcate HOT skills among students. They should imperatively act as reflective practitioners sharing their thoughts, providing conducive- creative classroom environment helping students in decision making. Teachers should provide equity in teaching tactics for an inclusive classroom helping all the students of different mental abilities to develop required physics HOT skills, with special attention to below and above average students. And one of the best ways is to start with classroom teaching and internal examinations having HOT skills orientation.

For students

Students also need to realize the importance of understanding rather than memorization. They should themselves think over its importance and focus on it. They should not just follow the blind marks- competition but focus on conceptual understanding in physics concepts.

For parents

Parents now days are dying for their child CGPA/ percentage/ranks etc. but are unaware of HOT skills importance. The whole society judges student capabilities only from their marks/grades and so creating more stressful situations for students. While many times high IQ students understand concepts, do not rote memorize and scores less in examinations with majority LOT skills questions. Such examinations can never assess thinking aptitude, HOT skills proficiency and future achievements. Parents need to encourage their children to develop higher order conceptual understandings not memorization. They need to understand HOT skills importance and help their children acquaint it.

Acknowledgements

In the last we specially thank all the experts who took out their precious time, reviewed our work and helped us in analysis and categorization of questions.

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A CONCEPTUAL TEST FOR THE PHYSICS LABORATORY: QUESTION-FRAMING AIDS ARTICULATION BUT ALSO REVEALS SUSCEPTIBILITY OF BELIEFS

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Students' responses to a question on a conceptual test on physics laboratory experiments revealed a significant variation in the way they understand the phenomenon of triboelectric charging of objects. Students attribute a combination of numerous factors such as friction, electronegativity, heat, "knocking off" of charges, formation of weak/temporary bonds, etc. as causes for the charging. While students sparingly mentioned their beliefs about these causal mechanisms in answers written in lab reports, a small change in question-framing and an additional question possibly induced them to express these beliefs in the conceptual test. However, students' adherence to causal factors was seen to be somewhat susceptible to the framing of the question. This suggests the need to create conditions for students to reflect more about laboratory work. We attempt to identify factors that could help address the deficiency in reflective practice/learning.

Introduction

According to government statistics (UGC, 2016), in India every year around 12 lakh students enroll in Engineering courses and 4 to 5 lakh students take physics in their first year of B.Sc. Most of them take a course in Mechanics and a course in Electricity-Magnetism in their first year. Given this scale, it becomes crucial that the design of the courses be made consistent with the results of research in cognitive science, physics education and science pedagogy in general.

Empirical research in physics education has shown that the traditional ways of conducting courses are less effective as compared to the interactive-engagement approaches - with the latter resulting in around double the normalized conceptual gain as seen in the former Hake (1998). People from universities around the world have designed and implemented ways of conducting physics courses based on active-learning (e.g. from the American context, Meltzer & Thornton, 2012).

To incorporate ideas from such work, we introduced some explorative portions in certain experiments of an Electricity-Magnetism lab course. We had observed that some students tend to not reflect while doing experiments and follow procedures with insufficient thought - as if they separate out the actions of thinking/reflecting and doing in the context of experimental work. We attempted to address this by choosing a particular order for the explorative experiments.

The assessment of a lab course is typically done with the lab report marks and sometimes additionally, a practical exam or/and a viva voce. To overcome certain drawbacks in each of these methods, we devised a conceptual test to evaluate students' understanding about the experiments that they had performed.

Here, we discuss students' answers (written in their lab reports) to a question about an experiment on triboelectric charging and their responses to a question related to the same experiment that was asked on the conceptual test. Certain observations and patterns from these responses give clues about potential ways to improve student reflection and conceptual learning of experimental physics.

Explorative experiments on electrostatics

The experiment was preceded by a 30 minute explanation-cum-discussion about the historical development of concepts and classic experiments related to electrical charge, its applications and relation to other phenomena and to everyday life. Since the previous academic year, we replaced an experiment to verify Coulomb's Law which had problems, with several short experiments which we hoped would help students develop a better physical feel for the concept of electrical charge. The experiments did not follow a textbook situation and the corresponding conceptual questions had non-standard answers. So we expected that students will write their own causal beliefs about these phenomena.

The experiment involved measuring the charge on various objects by dipping them in a Faraday cup (using the principle of electrostatic induction) attached to an electrometer amplifier in the charge-measurement configuration. It allows us to measure the charge on various objects which was typically a few to tens of nanocoulombs (see Appendix).

Below, we have an excerpt from the write-up of the experiment on electrostatics:

> a) Make a large soap bubble. Bring a rubbed plastic scale near it. Why does the bubble get distorted?
>
> b) How can we measure the charge on an object without discharging it? e.g. how will you measure the charge on the plastic scale?
>
> c) Hold a PVC rod in your hand and dip it in a Faraday cup. How much charge does it get and why does it get charged? How do we explain the sign of the charge on the rod?
>
> (In this part, we wanted students to realise that even if we simply hold a PVC object, it gets charged. Rubbing vigorously - like we have rubbed the plastic scale in part (a) is not necessary. In addition, the second question was meant to elicit the mechanisms that they attribute to the charging. However, many students simply relied on the empirical triboelectric series.)
>
> d) If we hold a plastic scale (that hasn't been rubbed) in our hand, does it get the same charge as a PVC rod? Why is the charge different?
>
> (We expected to reinforce that similar to PVC, polystyrene - the material of the plastic scale, also

gets charged (although less than PVC) by merely holding it.)

e) Using a high voltage tip, charge a brass ball (connected to a PVC rod) to -1kV. Measure the charge. Is it close to the theoretically expected charge? How many excess electrons are present on the ball?

f) Rub the brass ball with your fingers. Does it get charged? Explain.

We coded the answers to the question on holding a PVC rod (question c) into five broad categories. The numbers in the parenthesis indicate the number of students in the category. Eight students did not answer this particular question.

1) No mention of triboelectric series or any mechanism or property of the substances involved (4)

"PVC rod gets charged because some electrons are transferred from our hands to the PVC rod, hence giving it negative charge"

2) Only position in the triboelectric series. (12)

"In triboelectric series, skin is on the positive side and PVC on negative side"

3) Triboelectric series and electron affinity/tendency to take up electrons. (41)

"(The PVC rod), gets charged because it is at the bottom part of the triboelectric series. Human skin and hair being at the top part of the series, thus causes the PVC rod with higher electron affinity to become negatively charged"

4) Friction and triboelectric series/electron affinity/tendency to take up electrons (24)

"The PVC rod gets -12nC. The rod gets charged due to tendency to accept electrons from other objects. The rod gets high charge due to friction between the hand and the rod. The amount of charge just depends on the material of the rod"

5) Adhesive bonds and different tendencies to attract electrons (7)

"when two materials are rubbed against each other, a chemical bond is formed between the two surfaces (called adhesion). Charges move from one surface to the other along their potential gradient. It has been seen that synthetic polymers acquire negative charge due to their characteristic chemical structure and properties."

We can see that a large number of students are in category 3 – i.e., they do not simply give an empirical reason (triboelectric series) but also attempt to justify the differential charging with a physical property of electron affinity or tendency to attract electrons. However, they do not mention any mechanism for the separation of charges. Clearly, most students did not interpret the question, "why does it get charged" as a query about the causal mechanisms. Perhaps a "how" instead of the "why" might have worked or this may be an indication that students do not expect to be asked about mechanistic reasoning and interpretations in the physics lab. Category 5 had only seven students who gave a molecular/atomic-scale mechanistic explanation for the charging using a picture of adhesive bonds that are formed on contact, which are broken asymmetrically when two objects are separated.

A question on the conceptual test

Below, we have questions about triboelectric charging (See Appendix) that were asked on the conceptual test (See Appendix). The questions were slightly different from the lab experiment to elicit a clearer picture of how students understand this phenomenon. We introduced the action of "rubbing" in this question to see if the experimental evidence of part c of the laboratory experiment (which involved merely holding the PVC rod in the hands) has been well-appreciated by students. Please note that question d should also have helped students to realise that while they rubbed the plastic scale to charge it in question a, we can still charge the scale by simply holding it. We also asked about the nature of the forces involved in triboelectric charging with the hope that more students will write about the physical mechanisms - which was done by only seven students in category 5 of the lab report answers.

> "How does an insulator such as PVC get charged by rubbing it with our hands? What kind of force/s is/are involved? (Why can't we simply rub the brass spheres and charge them? Shouldn't it be easier since metals have "free" electrons?)"

We did not discuss the responses to the questions in parentheses. The responses fell into categories some of which were quite different from those in the lab report answers. In a way, richer details about their beliefs regarding the phenomenon emerged in the test responses. The numbers in the parenthesis indicate the number of students in the category. Four students did not answer the question. The categories were as follows:

A) Only electrostatic/electromagnetic force (8)

> "Because insulator does not have free electrons, if we transfer electrons to or from it, the charge will stay there only. Afterwards, even if the other part is grounded, due to lack of electrons it will stay charged. Force involved is electrostatic."

> "EM forces are involved. When we rub our hand with the PVC, the charges present inside the PVC will experience a force due to the charges present in our hand. This will cause the electron to get detached from the hand or PVC to the other one."

B) Triboelectric series/electron affinity/tendency to take up electrons (18)

> "The PVC rod will get negatively charged because PVC can accept electrons from other materials because lies low in triboelectric series. This is due to the presence of chlorine in PVC. Chlorine is electronegative. It can take electron."

> "When two materials are rubbed, electrons are transferred to the one which attracts electrons better."

C) Only friction (24)

> "It is easier to charge the PVC by rubbing with our hands as rubbing makes it easier to remove the electrons from the surface of PVC. The force involved is frictional force."

> "When we rub PVC with our hands, the electrons from our hand get dislodged due to friction and get fixed on the localized areas of PVC. Since PVC is an insulator, it is very difficult to remove the electrons. Friction is involved."

D) Friction and/as electromagnetic/electrostatic force. Do not explain the sign of the charge and do not mention triboelectric series. (15)

> "PVC gets charged when rubbed by our hands due to the transfer of charges (namely electrons) from our hands to the PVC rod. This method is called charging by friction. The force inherently involved is the electromagnetic force manifesting itself as friction and columbic attraction."

> "Insulators such as PVC get charged by rubbing due to friction. Friction itself is an electrostatic force of attraction. On rubbing, the charges which were fixed earlier are moved around. After rubbing, they cannot go back to their original orientation, being an insulator."

E) Heat/energy by rubbing to escape/to break bonds. Do not mention electron affinity or triboelectric series or sign of charge (9)

> "It is possible because rubbing with our hands vigorously produces heat which in turn can rip off electrons from the atoms on the surface. Thus they get charged. The forces in play are friction and mechanical forces."

> "On rubbing, we are providing energy which can be enough to ionize the electrons and knock the electrons free. This creates charges which are bound (not flow). Hence PVC is charged."

F) Heat/energy due to rubbing/friction and triboelectric series/electron affinity/tendency to take up electrons (12)

> "On rubbing, insulators get heated up due to friction and thus vibrations are faster and electrons get detached depending upon relative charge losing tendency."

> "If we see the triboelectric series, then we can find dry human skin at the top and PVC at the end. Meaning, human skin is a good electron donor and PVC is a good electron acceptor. Thus, rubbing PVC with our hand generates heat due to friction, due to which, some electrons get loosely bound. Since PVC has much higher electron affinity, thus it will take up those electrons and become charged."

G) Bonds are formed and broken + triboelectric series/electron affinity/tendency to take up electrons (6)

> "The effect involved is called triboelectric effect. When PVC is rubbed with our hands, it forms temporary weak chemical bonds with the surface of our hand. As this breaks off, electrons associated are distributed unequally according to the properties, resulting in charge."
>
> "When we rub the PVC with our hands, they come into very small distances where bonds are formed and broken when we move our hand. As the PVC lies towards the negative end of the triboelectric chart, it is more electronegative. So when bonds are broken it tends to keep the electron to itself. It gets negatively charged."
>
> "The molecules constituting the PVC form adhesive bonds with the molecules of our hand and due to a difference in electrochemical potential we get a transfer of electrons from our hand to the other. The forces involved are van der Waals and London forces."

Discussion on students' responses

We cannot directly compare the answers from the lab reports and the conceptual test as the questions are slightly different. However, a small difference in framing seems to be enough to induce some students to change their answers to completely new categories. The small change in framing to include "rubbing" and the additional question on the forces involved, possibly induced almost all students to articulate their beliefs about the underlying causal mechanisms.

A few completely new mechanisms for charging were proposed in the responses to the question on the conceptual test. 21 students (category E & F) postulated that the heat generated due to rubbing will increase the bond breaking, thus releasing electrons.

We can see that categories 2 & 3 of the lab report answers (triboelectric series and electron affinity) have shrunk and split into categories B & F of the conceptual test. The number of students has shrunk from 53 (12+41) to 30 (18+12).

The last categories of answers of both the lab experiment and the conceptual test had almost the same students who stuck to their answers. Category C & D consisting of people who attributed charging to friction had 39 (24+15) students. Whereas only 24 students in category 4 of the lab report answers believed in a friction hypothesis. It is possible that students simply changed their answers to friction because the test question had the word "rubbing".

This wide variation in the causal factors suggests a nuanced picture of how students understand physical phenomena in a laboratory. The exploratory and tactile nature of the experiment and the familiar yet non-standard nature of the concepts involved, apart from the framing, possibly give students an opportunity to formulate their own hypotheses Etkina (2007) about the phenomenon.

Promoting reflection on lab work

We see that while appropriate framing can aid articulation of causal beliefs about physical mechanisms, students' adherence to previous responses to conceptual questions, can be susceptible to the framing of questions. While this may be limited to concepts like triboelectric charging, the fact that many students changed their causal categories in the conceptual test even when they had access to their own lab report answers (it was an open book exam), might indicate that they do not reflect sufficiently on the experiments that they do in the lab. Students' reflection on their work is crucial for effective learning, Parry (2012) and concept-formation and hence, the barriers need to be identified. A combination of the following and other factors have to be investigated and addressed to remedy the situation:

i) Not everyone finds physics engaging - An ethnology of participant-observer non-science majors who audited introductory college science courses mentions several factors that block student engagement Tobias (1990).

ii) Busy schedules - e.g. at our institute, the first-year students attend classes or work in labs from 8:30 AM to 5 PM all the five days in a week. There are continuous homework submissions, lab reports and preparations for tests for most of the six courses that they take in a semester. Some senior professors have remarked that the semester system leaves less time for self-study.

iii) Especially, in physics courses, there is less precedent of students being expected to consider competing causal hypotheses. The instructional mode of teaching is the prevalent and dominant one in which most of the reasoning and logic is supplied in the lecture.

iv) The sheer volume of taught material across the different courses proves overwhelming enough to thwart students' attempts to reflect on what has been taught.

v) Widely held misconceptions about the Nature of Science that science is merely a body of knowledge and not the processes and practices that are involved in a scientific investigation Wong (2009). The hegemony of the 'science as a body of knowledge' paradigm also denies agency to the learners to reason on their own. Physics being the oldest science, has the additional burden of 'covering' more subject-matter - which reinforces the hold of this paradigm.

Besides creating conditions for student reflection, there is a need to incorporate in a lab, the paradigm of qualitative and conceptual understanding of physical phenomena. Extensive research in the field of conceptual change has established that students are not empty slates that they have their own concepts about phenomena that these alternative conceptions are robust and difficult to replace with the "correct" ones. However, it is impossible to identify each and every such instance. Considering this and in the light of the empirical evidence previously mentioned, a transition to a more interactive (and democratic) paradigm of teaching-learning is crucial. This might give access to a mechanism of identifying and working on these alternate conceptions for which, methods to provide formative feedback to students during the semester need to be developed. Additionally, critical discussions about phenomena (Hake, 1992 and Duckworth, 2005) can promote engagement and agency in students.

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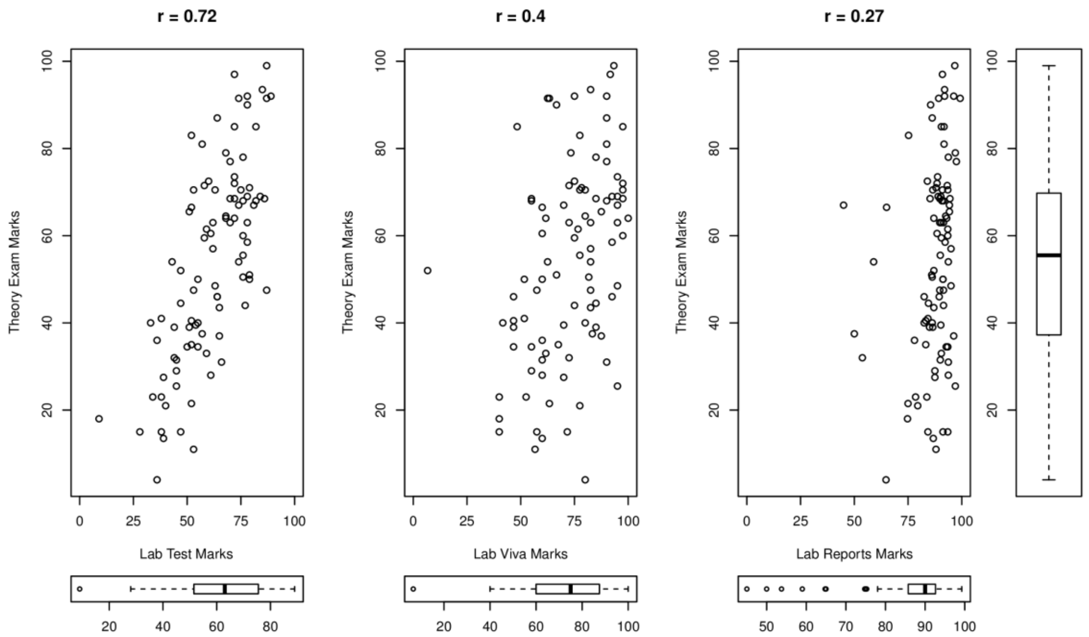
Appendix: A conceptual test for the physics laboratory

We encountered a number of problems with assessing students for their performance in the lab. Lab report marks are not a good criterion because they tend to be inflated and less spread out. Conducting a viva voce gives examiners a better and more direct way to assess students' understanding of the experiments. It can also be an opportunity to provide formative feedback during the semester. However, examiner-fatigue and saturation of possible questions can make the viva scores less dependable. Conducting a practical exam by repeating the experiments or with related but new experiments often runs into problems of logistics. Also, it is difficult to keep all the experiments at the same level of difficulty.

We devised a conceptual written test to evaluate students' broad understanding of the experiments. The test had questions on derivations, estimation and descriptive questions about physical principles, design of experiments and cause-effect relationships. It was an open-book exam for two hours. Students were allowed to bring their own lab reports and the experiment write-ups. The scores in the conceptual test were strongly correlated with the theory scores (Pearson correlation coefficient = 0.72). In comparison, the correlation coefficients of the other assessment criteria with theory scores were much lower (0.4 and 0.27 for viva voce and lab reports respectively). Only the sum of the midterm and final exam theory marks were considered (the scores in a theory homework assignment were not considered).

The graphs given underneath imply that the conceptual test might be a better indicator of understanding of physics. Box plots of the various lab scores are also included to indicate the median value and the quartiles. While evaluating descriptive questions is critiqued for being time-consuming, we feel that it is only fair that institutions allocate sufficient resources for better conceptual evaluation.



Friction and triboelectric charging

The responses to the question on triboelectric charging reveal a gap in understanding about the nature of this phenomena and suggests weak concept formation about the relation between triboelectric charging and friction. However, all the causal mechanisms suggested by the students in their answers happen to be relevant and applicable in different scenarios of triboelectric charging ("Triboelectric Effect," 2017, "Cause," para. 1 & 2). It has been acknowledged that though the phenomenon of triboelectric charging is commonplace, it is not really well-understood (Horn, 1992, p. 362).

Both, friction and triboelectric charging have their origin in the molecular/atomic-scale interactions between surfaces. They are related and entangled in the sense that both involve the formation and breaking of weak temporary bonds between surfaces in contact. They are never discussed or taught simultaneously simply because one is a topic in Mechanics and the other in Electricity-Magnetism. Triboelectric charging is not discussed in the popular textbook on Electricity-Magnetism by David J. Griffiths, neither does Feynman mention this phenomenon in his lectures. While Feynman acknowledges the non-trivial nature of friction in full measure (Feynman, 1964), the textbook on Mechanics by Kleppner & Kolenkow however, doesn't discuss these issues in as much detail. Perhaps, the over-familiarity with the phenomenological model of friction hinders deeper reflection on and appreciation of the molecular-level mechanisms. The mutual relationship between friction and triboelectric charging is a subject of current research (eg. Burgo *et al*, 2013).

Constructing a simple Faraday cup electrometer

To construct an inexpensive Faraday cup, we can add a metallic cylinder, e.g. by cutting a soft drink can, and a grounding metal rod to the electrometer amplifier as explained in Raghavendra, M. K. & Venkataraman, V. (2014) on the lines of a commercially available Faraday cup electrometer, say LD Didactic (n.d.).

USE OF TARSIA GRID AS A TEACHING AID TO FACILITATE ACTIVE LEARNING IN CHEMISTRY EDUCATION

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Use of teaching aids in engineering education is swiftly changing from blackboard to virtual simulations and newer teaching methodologies so as to make the learning process more enjoyable. Games form an interesting avenue for teaching-learning process as they evoke interest, motivate students and are a welcome change in the monotonous routine lecture teaching formats. Activities such as show me board, DART (directed activities related to texts), concept maps, bingo and card sort are being used now to engage students in the subject and enjoy learning. This paper describes the use of Tarsia grid as a revision tool for making the learning process more enjoyable among the first year engineering students. A first year class consisting a strength of sixty students were given the task of arranging the Tarsia triangle in the topics, namely phase rule, lubricants and adhesives. The students did it with great enthusiasm and it was a new experience for them. The outcome of the study is encouraging and the students wanted it to continue for other topics too.

Introduction

The primary mode of curriculum delivery in chemistry classes has traditionally been in the form of didactic lectures, where the teacher has the central role and students were passive listeners. In the present day scenario, more emphasis is laid on creating learning environment which are student centered and facilitate active learning. Incorporation of active-learning methods into classroom allows lecture formats to engage students in the learning process and make their learning experience more effective, efficient and meaningful. Active learning promotes acquisition of generic skills, communication skills, cooperative learning, critical thinking and self-directed learning.

Several empirical studies have shown that incorporating active learning helps motivate students and improve their understanding and learning (Saxena et al, 2009). During the last decade, research revealed the benefits of games and puzzles, forms of active learning on intrinsic motivation and deep learning (Burguillo, 2010; O'Leary et al, 2005; Bailey et al, 1999; Vos et al, 2011). Educational games introduce fun element into the lesson, which can help to generate more positive feelings about the subject matter and to enhance learning outcome. In the search for innovative activities to enhance student motivation and facilitate learning, puzzles are considered to be effective learning tools in disciplines such as medical education, psychology (Crossman & Crossman, 1983), sociology (Childers, 1996), communications (Whisenand & Dunphy, 2010), nursing (Raines, 2010) and biology (Franklin et al, 2003) among others.

The Tarsia grid (puzzle) is a novel and unique idea designed to enhance the student learning experience. The puzzle is made up of a series of 'paired statements' or 'question and answers' or 'key word and definition' that appear to be randomly arranged on a series of geometric tiles e.g. triangles, and is solved by matching the pairs. As the pairs are correctly matched up one by one, a larger tiled pattern emerges. Tarsia puzzles are fun to do and generally students find them much more engaging than simply working through a series of questions. It also helps to develop their thinking skills as they work through problems. They are particularly useful for doing revision.

Construction of Tarsia grid

Tarsia grid puzzle is designed within the physical chemistry unit (Engineering chemistry- Unit-III). The question and answers are constructed around words representing essential concepts and connections between them, and terms and definitions that are required to be frequently recalled. To create question and answers, we sought to represent not only the classification category, but also used definitions. Some questions are designed to challenge students semantically and to provide an opportunity to learn the importance of content.

The Tarsia contains 20 questions each. The Tarsia grid (puzzle) were composed by one of the author and validated by another author. The construction of Tarsia grid involved four steps.

Step 1: Writing down a list of 'paired statements'. It is important that each statement only has one possible 'paired answer' otherwise the overall title pattern will not work (Table 1).

Step 2: Transferring the information from the table onto a blank template by writing each pair of statements on either side of the border tile lines.

Step 3: After completing the template, required copies can be made.

Step 4: Individual triangular tiles are cut. Care to be taken not to cut through any of the statements. Finally a puzzle is ready to use.

Table 1 presents the questions and the correct answer for the questions. Figure 1 exemplifies the completed Tarsia grid with questions matching with correct answers.

Formula for phase rule	F= C-P+2
Formula for reduced phase rule	F= C-P+1
Example of one component system	Water system
If the degree of freedom in one then the system is	Univariant
The point at which three phases co-exist in equilibrium	Triple point
No. of phases in the water system Ice $\rightleftharpoons$ Water $\rightleftharpoons$ Water vapour	3
Example of Two component system	$CaCO_3 \rightleftharpoons CaO \rightleftharpoons CO_2$

Example of simple eutectic system	Lead-Silver
Desilverisation of lead in lead-silver	Pattinson’s process
Grease	Semi-solid
Solid Lubricant	Graphite
Constant temperature at which liquid having the same composition as that of solid	Congruent melting point
The temperature at which oil ceases to flow	Pour point
Study the cooling curves	Thermal analysis
P=3, C=1	Invariant
To reduce frictional resistance	Lubricant
Pensky Marte’s apparatus	Flash & Fire
Araldite	Epoxy resin

Table 1: Paired questions-answers

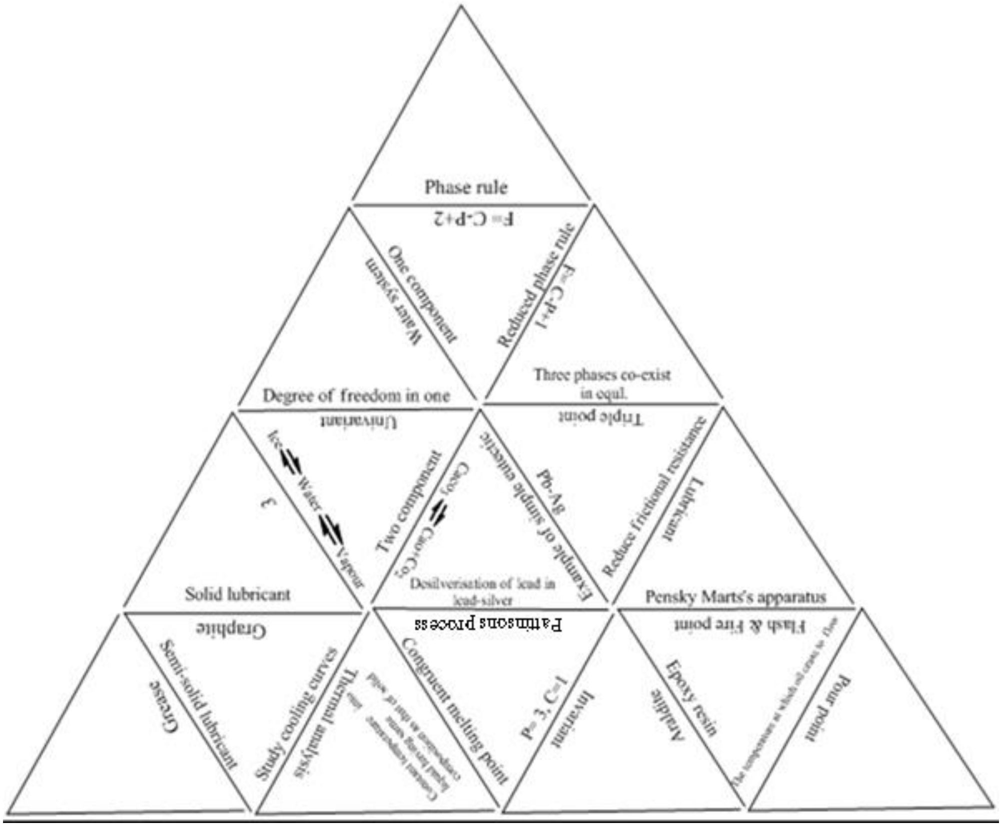

Figure 1: Constructed Tarsia Triangle

Methodology

The study was conducted with first year engineering students, consisting of 60 students who were given the task of arranging the Tarsia triangle. The topics included were phase rule, adhesives and lubricants. These topics were already taught in the class but the students found it difficult to understand and remember. Tarsia grids were evaluated as a revision tool and a study aid. This fun activity was practiced after the portions were completed. The sixty students in the class were grouped into ten groups, each having six students. A single large triangle was split up into 20 pieces of small triangles in the chart with question and answers. These 20 small triangles were given to the students of all the ten groups for proper arrangements.

Figure 2 shows the students involved in solving Tarsia grid. Group discussions were encouraged while solving the Tarsia to promote collaborative learning. Time given for solving the crossword was 20 minutes. At the end of the allotted time, correct answers to the Tarsia puzzle were discussed. This method of learning helped the students get involved.

At this stage of the project, we have examined two aspects of Tarsia grid implementation:

(i) the degree to which the students were engaged with the tool, and
(ii) how efficient it was for the development of their learning abilities.

Figure 2: Students solving Tarsia grid puzzle

Results & Discussion

A pre-validated questionnaire consisting of 7 items was used to record students' perceptions about the Tarsia grid puzzles, and their responses to the items 1-7 are expressed as percentages in Table 2.

The Tarsia grid activity was very well received by the students, and was perceived to be challenging.

Almost all of them (95%) strongly agreed that solving Tarsia grid puzzle was a fun experience and they enjoyed learning through creation. Majority of the students (92% of responses) strongly thought that their understanding of the topic had improved as a result of the Tarsia activity, and also felt that the core area of the topic was emphasized by the clues provided in the puzzle solving. The feedback also indicated that the students were motivated and interested in the topic being studied with the help of the Tarsia grid, and they were able to remember important terms therein. Finally, most students (90%) favoured the incorporation of tarsia grid puzzles in the curriculum.

No.	Statements	Percentage (%)				
		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	Fun filled experience to solve Tarsia grid	0	0	0	5	95
2	Improved my understanding of the topic	0	0	0	8	92
3	Promoted active learning	0	0	3	7	90
4	Helped to remember important terms from the topic	0	0	5	9	86
5	Emphasized core area of topic	0	0	5	8	87
6	Incorporation in the curriculum to encourage active learning	0	0	3	7	90
7	Enjoyed learning through recreation	0	0	2	6	92

Table 2: Student perceptions of Tarsia grid as teaching tool (N=60)

Conclusion

Use of Tarsia grid as a revision tool in chemistry teaching can be an effective alternative means to relieve the tedium of taking tests for revising the subject content, in a more relaxed and friendly atmosphere in the classroom. Further, it also facilitates active learning and makes the entire experience more productive and engaging, with the puzzle element. The Tarsia grid game is an interesting and fun way of teaching a subject matter. In this study, we have attempted to rationalize the effectiveness of Tarsia grid as a tool for learning and revision. Students enjoyed using the activity for revising the topics they have learnt and recommended its use for other chapters and in future semesters.

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INDIAN K-12 PHYSICS EDUCATION: THE ROLE OF GENDER AND LANGUAGE

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A systematic study of students' knowledge of mechanics at the higher secondary school (K-12) level is undertaken using a well-established tool, namely the Force Concept Inventory (FCI). The focus is on students from bilingual (English-Hindi) and solely vernacular (Hindi) medium of instruction. The role of gender is also probed. The number of students involved in the study is 581. The fact that on an average boys perform better than girls has been noted abroad and is also observed in our work with an important exception. In schools where the overall performance is below par, girls out-perform boys. The study is part of our ongoing effort in PER but specifically probes the role of the vernacular medium and gender.

Introduction

Some four decades of Physics Education Research (PER) has revealed that students have pre-set ideas on how physical systems should behave prior to their study and these are robust and hard to eliminate. A trunk sliding at a high and constant speed must have a greater force acting on it than a smaller, slower wooden block; on a wintry day the metal handle of the rural hand pump feels colder to the touch than a bamboo stick as it is at a lower temperature; the force is invariably in the direction of motion; if the upper half of a lens is blackened the image it produces is suitably sliced off – all these are misconceptions we may hold onto despite a good grounding in high school physics.

We investigate hitherto unexplored aspects of higher secondary school science education in India which we shall call K-12 to conform to international nomenclature. Popular literature presents a confusing picture. On the one hand, Indian students have over the years made a significant impact as human resources in the fields of science and engineering around the world. Notable among these are the contributions of the Indian Institutes of Technology (IITs) (Friedman, 2007; Stahl, 2003). On the other hand there exist dismal rankings in international assessments like PISA (Programme for International Student Assessment, www.pisa.oecd.org). We focus on the final two years of K-12 level as it marks a watershed in the country's education system. In all likelihood the English educated upper class and admittedly, highly motivated students from metropolitan areas contribute to the rosy picture.

The grim reality is that the majority of the K-12 students are in vernacular or at most bilingual (mixed English-vernacular) schools stagnating in weak, moribund and listless environments. The role of gender and contextualized learning has attracted increasing attention over the years (Rennie et al, 1996; Ederstein et al, 1998). The need to probe physics misconceptions and to remedy them particularly amongst girls, the under-privileged and the students groomed in the vernacular language is important and does not require a justification. The present work is step in this direction and is evidence of our continued commitment to this area of study.

K-12 science education in India falls mainly under the purview of a national board (Central Board of Secondary Education, CBSE). In addition each state has its own board. Schools affiliated to CBSE follow textbooks designed by the National Council of Education Research and Training (NCERT), which also serves as the basis for most of the state curricula. Physics is taught as part of a general science subject up to grade 10. Thereafter, in grades 11 and 12 it is taught as a separate subject for students opting for the Science stream as distinct from the Commerce and the Arts-cum- Humanities streams.

We draw attention to another aspect of Indian science education. The drive to qualify in the competitive exams has given rise to a *parallel education* system. Students attend school but they also enrol in privately run coaching centres where detailed and intensive instruction is provided along with a heavy emphasis on memorizing and problem solving. Also known as *shadow education*, these private coaching centers are to be found in all parts of the country (Bray et al, 2012).

Methodology

The diagnostic instrument we employed in our study is called the Force Concept Inventory (FCI) (Hestenes et al, 1992). The FCI essentially comprises of a set of 30 carefully crafted multiple choice questions aimed at probing students' conceptual understanding, eliciting misconceptions and ferreting out their flawed reasoning patterns in the area of mechanics. Concept Inventories (CIs) have played an important role in stimulating science education based reforms in the USA (Hake, 2011). They have been employed to assess the efficacy of instructional modes and curricula. A CI whose validity and reliability has been tested is a versatile diagnostic instrument for instructors and a science education researcher which works equally well at the individual and mass level and is suited for Indian conditions (Singh, 2011; Mashood et al, 2015). The FCI is recognized to be global benchmark test in mechanics covered at the K-12 level (Crouch et al, 2011). A word about the nomenclature: an inventory is sometimes called an instrument or test and the questions are called items.

Timings and incentives in conducting tests can impact test results (Ding et al, 2008). The FCI is a conceptual test with minimal reliance on memory. Our objective was to evaluate how robust this understanding is. Hence we waited for a period of three months after the subject had been taught before administering FCI as a post test. No incentives were offered to the students in terms of prizes for good performance or increased grade points in end semester grades. The students were asked to answer all questions in the light of their understanding and to avoid guess-work. There were no time limits imposed on the students, however we found that students took an average of 45 minutes to answer the 30 questions. The entries made by students regarding stream (see below), gender, etc were cross-checked by invigilators while the test was being taken. The family income data provided by the students was voluntary and confidential. We were however able to gauge the financial status based on the fees the school charged as well as the localities the students came from. On request, about 15% students agreed to come back and be interviewed. This was done after we had scrutinized their responses.

Results

The students we surveyed are from Patna, India (a class A city), and its surroundings. A total of N = 581 students were surveyed, categorized as:

1. Bilingual N_B = 461. These students were in nominally English medium schools. But the instructors teach in a mixed English and Hindi mode. The textbooks used were NCERT English medium (NCERT, 2006) with local Hindi book as a supplement (NCERT, 2006; Kumar et al, 1991; Agrawal et al, 2016; Sinha et al, 2017). These students fell into two distinct subcategories.

(a) Those who had chosen the **Maths**-Physics-Chemistry combination. These were N_{BM} = 362. **(b)** Those who had chosen the **Biology**-Physics-Chemistry combination. These were N_{BB} = 99.

2. Hindi N_H = 120. These students were in Hindi medium schools. The schools were Government run and follow the State Board norms. It may be pointed out that the State Board of Bihar has officially adopted the CBSE syllabus and the NCERT books. Thus nominally these students were taught the same topics in Physics as the bilingual students mentioned above. In practice they relied on the locally available Hindi medium books mentioned above. The schools cater to the low income groups. These students also fell into two distinct subcategories.

(a) Those who had chosen the **Maths**-Physics-Chemistry combination. These were N_{HM} = 90. **(b)** Those who had chosen the **Biology**-Physics-Chemistry combination. These were N_{HB} = 30.

	Number	**Boys**	**Girls**	***A***	***ABO***	***AGL***
N	581	306	274	11.14 (±6.355)	12.94 (±7.151)	9.13 (±4.467)
N_B	461	236	224	12.90 (±6.224)	15.50 (±6.140)	10.15 (±4.127)
NBM	362	204	156	13.64 (±6.313)	16.73 (±5.656)	9.60 (±4.127)
NBB	99	32	68	10.22 (±6.607)	7.68 (±1.827)	11.41 (±3.866)
N_H	120	70	50	4.38 (±4.488)	4.26 (±2.377)	4.56 (±1.442)
NHM	90	59	31	4.71 (±4.464)	4.35 (±2.377)	5.40 (±1.556)
NHB	30	11	19	3.40 (±4.51)	3.77 (±1)	3.19 (±0.699)

Table 1: Results at a glance

The number of students (N) and their average scores (A). The numbers in parenthesis are standard deviations. The subscripts 'B', 'BM' and 'BB' stand for Bilingual students , Bilingual Maths students and Bilingual Biology students respectively. The subscripts 'H', 'HM' and 'HB' stand for Hindi students, Hindi Maths students and Hindi Biology students respectively. The subscripts BO and GL stand for boys and girls respectively. Students who left more than two items unanswered have not been included in the enumeration.

The highest possible score is 30 and 4 students from the Bilingual schools attained 29 while 8 students (all from Bilingual schools) scored over 26. The average from the Bilingual school (12.90) is clearly over the Hindi schools (4.38). However the overall performance is below what we have found in private English medium schools (Mashood et al, 2015) from Class A cities. We analyze the gender and language issues in the next sections.

Gender: paradoxical results

There has been an increasing debate regarding the small representation of women in the Indian scientific establishment. The concern regarding female performance in various competitive exams has also been raised from several platforms. However there is a significant absence of systematic study in this regard. A recent study presents a comparison between three national level exams which are conducted on higher secondary or pre- university level (Singh et al, 2010). Two of these exams are extremely competitive and the other was a standard test by the State systems. The study found that girls performed better in the standard State exams but very few succeed in the competitive exams and fail to secure admissions to top level science and engineering colleges.

Our results in Table 1 reveal a similar puzzling feature. The bilingual students perform better in FCI than the Hindi medium. The boys perform significantly better than girls among the bilinguals. However, in the Hindi medium, whereas the overall performance is below par (the highest score is 13 as opposed to 29 in the Bilingual category), the girls perform better. The same pattern is repeated in a subcategory of bilingual students, mainly those who opted biology over maths. The performance of this category is below that of the maths students as revealed in row 5 (N_{BB}) Table 1. Here once again the performance of girls is superior. The performance of students in the Hindi speaking biology stream (last entry in Table 1) is very low and within statistical fluctuations and definitive statements of boys vis-a-vis girls cannot be made.

A possible explanation for this lies in the lack of parental and societal interest in quality education for girls. During post-test interviews, the bilingual biology subcategory of students was asked if they had a remedial maths or physics classes or went to a coaching institute. 70% replied in the negative. On the other hand when the maths subcategory was asked, the answer was 90% in the affirmative. The Hindi medium students were uniformly from a lower income group and could not afford good coaching institutes. In a study using FCI and several other standardized tests it was found that the students availing of special coaching did markedly better (Mashood et al, 2015). It appears that when students were left to fend for themselves, the girls did better than the boys though their performance is nevertheless below par. This was corroborated by interviews with 15 teachers and two school principals in these lower income, Hindi medium schools. Phrases, such as, "the girls work hard", "they are disciplined", "they are punctual and attentive" as compared to boys, were common. In this connection it is interesting to note that Doctor and Heller found that although girls consistently under-perform vis-a-vis boys in FCI, they do as well as them in course performance (Docktor et al, 2008). They attribute this to the fact that the grade includes inputs such as laboratory reports and other forms of participation and hence achievement is linked to diligence. It is interesting that the observation that female students in science are more “diligent” is a theme common to both the US and India.

A possible reason for the inferior performance of girls among the bilingual maths subcategory is the nature of FCI. Some studies suggest that the context of the the questions can affect student performance. The FCI posits situations, such as rocket (items 21-25) or cannonball (item 12) in motion, situations where boys would be more at ease. Item 25 describe a woman moving a heavy box, somewhat unrealistic and could be replaced by a woman moving a sofa in her drawing room. McCullough has listed additional situations and has suggested alternative wordings [https://kellymccullough.com/wp-content/uploads/2016/09/AAPT-Jan01-SanDiego-GFCI.pdf]. Our problem with these suggestions is that they too are very much USA-centric. For example replacing a cannon ball with a teddy bear which is flung horizontally is not desirable. The teddy bear is as foreign to a lower income girl from a semi-rural area in India. One may not accept these arguments but it does indicate that a rethink of context and sensitivity to language is desirable in designing concept inventories (Majors, 2015).

Language

It is clear from Table 1 that the Hindi medium students perform significantly below par. Whereas the highest score among the Bilingual students is 29 (full score), the highest in this case is 13. A primary reason is language but other contributory reasons such as income, lack of learning facilities like library and laboratory, poor instructors etc cannot be ruled out. Below we address one issue, namely language.

The role of language in understanding science is indispensable. Celebrated instances concern light and vision. Whether light emerges from the eye and illuminates an object and hence enables vision (extra-emission) or light scatters off an object and reaches the eye to produce vision (intro-emission) has been a pivotal point of discussion for around a thousand years. The Hindi language would tilt the scale in favour of the (false) extra-emission theory. Another example is the use of the term ray for alpha and beta rays which are in fact particles. Or the use term radio-waves which seems to suggest that they are sound waves.

Underprivileged students studying in vernacular media are particularly susceptible to such misconceptions. After interviewing the students who took the FCI we documented the following instances where the language in the FCI proved to be an impediment. Four items (8-11) in the FCI used the example of the hockey puck. The hockey puck is used in ice hockey and the idea is to have a light body moving on a frictionless horizontal surface. But the situation is unfamiliar to Indian students and so is the term “puck”. In a pilot study we replaced this situation with a carom board. This is a game in which plastic or wooden coins are struck with a heavier plastic coin (called the striker) on a smooth wooden board. In another pilot study we had marbles (small glass balls) being struck by a heavier marble. Another item concerned a bowling ball falling off from the cargo bay of an airliner in flight (Item 14). The notion of a bowling ball is foreign to our students. We replaced it with the example of a stone being dropped from the doorway of a moving train. The pilot studies we have conducted with these “translated” questions have been encouraging. But a systematic study needs to be done. We are in the process of constructing an FCI like inventory where the examples and contexts are Indian and also gender friendly. The lack of space does not perrmit us from elaborating on some features.

Conclusion

Inventories are an effective way to monitor and improve the teaching-learning process. They are objective and scalable. It is for this reason that we have adopted them. One criticism of our approach is that our numbers for the Hindi medium students are small. This is a preliminary study and we are currently carrying out larger studies. We also plan to apply inferential tests such as ANOVA. Our work should be viewed as an ongoing and open ended exercise.

In 2007 we reported a large scale survey of student's knowledge of friction (Singh et al, 2007). We have reviewed its use (Singh, 2011) and developed one on rotational dynamics (Mashood et al, 2007). The latter was tested extensively in English medium schools of Class A-1 and Class A cities. The present work is a nascent effort to extend it to the vernacular environment, an effort, which in the long run should yield rich insights. In particular we mention some recent work which may prove helpful (Docktor & Heller, 2008, https://kellymccullough.com/wp-content/uploads/2016/09/AAPT-Jan01-SanDiego-GFCI.pdf; Mashood et al, 2016).

Acknowledgements

One of us (Vijay A. Singh) acknowledges support from the Raja Ramanna Fellowship by the DAE. Helpful discussions with Laura McCullough over email are gratefully acknowledged.

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AN EXPLORATORY STUDY ABOUT STUDENTS' MISCONCEPTIONS IN CHEMISTRY

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Research on students' alternative conceptions has proliferated in the last twenty years and enhanced our understanding about the preconceptions, misconceptions and alternative conceptions that students bring with them to the classroom. By now, it is well accepted that alternative conceptions and misconceptions are common among students, that these interfere with subsequent learning and are resistant to change. This exploratory study investigated misconceptions/ misunderstandings held by first year pre-service science teachers (B.Sc.B.Ed. students) of Regional Institute of Education, Ajmer in basic chemistry topics.

Introduction

The study of misconceptions in introductory chemistry among students is an important concern of Chemistry Education Research as well as a valuable tool for practicing chemistry teachers (Kind, 2004). Even when some students give the correct answers, they are often only using memorized words. Upon further probing, their failure in understanding the underlying concepts fully is revealed. Many students are unable to construct appropriate understanding of fundamental chemical concepts from the very beginning of their studies (Gabel et al 1987). Therefore, they cannot fully understand the more advanced concepts that are based upon these fundamental concepts. This study aims at identifying and analysing misconceptions/ misunderstandings in chemistry among first year pre-service science teachers (B.Sc.B.Ed. students) of Regional Institute of Education (RIE), Ajmer.

Methodology

83 students from the four-year integrated B.Sc.B.Ed course at RIE participated in this study. These students, in the age group of 17-19, largely represent northern India. From the sample of 83, 40 students had previously studied PCM (physics, chemistry and mathematics), while the remaining students (43) studied PCB (physics, chemistry and biology) in their pre-university (Class 12).

Data was collected using a bilingual questionnaire (English-Hindi) comprising 30 multiple choice questions, as some of the participants came from a Hindi medium of instruction.

This questionnaire was developed in workshop mode at the RIE, involving selected faculty members from the Regional Institutes of Education, National Institute of Education and retired faculty from the National Centre for Educational Research and Training (NCERT). Initially, 50 items for the questionnaire were prepared, from which 30 were agreed upon and finalized. The questions covered concepts related to states of matter (6 questions), atomic structure (10), chemical bonding (11) and mole concept (3). These topics are some of the core topics for secondary and higher secondary chemistry syllabi. Students were expected to provide written explanations for their choice of answers. The time allotted for completing the questionnaire was 45 minutes.

This paper primarily presents the qualitative and quantitative analysis of the responses for the topic of atomic structure.

Results & Discussion

Student responses were first examined on the basis of correct choices. The topic-wise mean scores and overall mean scores for the questionnaire for both groups are presented in Table 1. The low total mean scores indicate that the overall performance of the students on the questionnaire was poor.

	Mean scores				
Group	**Atomic Structure**	**States of Matter**	**Mole concept**	**Chemical Bonding**	**Total score**
PCM students (N=40)	4.52	2.7	1.55	4.97	13.77
PCB students (N=43)	4.09	2.32	1.20	5.10	12.72

Table 1: Mean scores obtained for each topic and total scores for both groups

The written explanations to the responses were also evaluated with the following classification criteria: sound understanding, partial understanding, partial understanding with specific misconception, specific misconception, and no response/ no understanding. These criteria are adopted from the work of Abraham et al (1992), Calık (2005) and Unal et al (2002). Some of the explanations, even though did not exhibit misconceptions, presented partially or fully incorrect explanations.

As seen in Table 2 below, there was no significant difference between the mean scores of PCM and PCB groups (as observed from the calculated t-value (p=0.05)).

Group	**N**	**Mean (from table 1)**	**SD**	**Df**	**t-value**	**Remark**
PCM	40	13.77	3.17	81	1.55	Not Significant at 0.05 level
PCB	43	12.72	2.98			

Table 2: Comparison of PCM and PCB groups using t-test

Atomic structure

Atomic structure is one of the core topics studied at pre-university level and forms the foundation for various concepts in chemistry. The questions covered on atomic structure pertained to Rutherford's atomic model, Bohr's atomic model, valency, isotopes, energy levels and electronic configuration. Among the 10 questions, the paper presents the analysis of 8 questions. The other 2 items could not be considered as they turned out to be ambiguous, and thus students' responses could not be categorized satisfactorily. Table 3 presents the distribution of students' responses for these 8 items.

Questions on Atomic structure	**Sound understanding (SU)**	**Partial Understanding (PU)**	**Partial understanding with Specific misconceptions (PUSM)**	**Specific misconceptions (SM)**	**No response or not answered (NR/NU)**
	In percentages (rounded to the nearest integer value)				
1	54	20	5	20	-
2	35	51	13	18	1
3	54	6	32	6	1
4	51	25	24	-	-
5	32	25	18	23	1
6	36	13	40	5	6
7	67	11	17	5	-
8	36	11	40	13	-

Table 3: Classification of students' responses to questions on atomic structure

Table 4 describes some of the questions, their themes, and the prominent misconceptions/ misunderstandings identified from the responses.

No.	**Item**	**Theme**	**Misconceptions/ misunderstandings identified**
1	Which one of the following is the most appropriate about Rutherford's Atomic model of atom? a) size of nucleus in an atom is very small in comparison to the	Rutherford's atomic model	"*Rutherford's model was given to explain about plum pudding model in which electron were embedded in positively charged nucleus".* *"Rutherford's model explains that*

	size of the atom b) electrons revolve around the nucleus in an atom c) both A & B d) the nucleus of an atom is a positively charged sphere with electrons embedded on its surface		*nucleus in an atom found to be in a corner adjoin to circular path so most of α- particles passed it".*
2	According to Bohr's atomic model, an orbit is a: a) stationary energy state and circular in shape b) energy state in which columbic attraction between electron and nucleus is equal to centrifugal force c) both A and B d) stationary state with elliptical shape	Bohr's atomic model	"*According to Bohr's atomic model stationary states are elliptical". "Electron is fixed in that orbit which is of fixed size". "Bohr's atomic model gave the shape and orientation of nucleus, electron in an atom".*
3	In Bohr's atomic model, on moving away from the nucleus of an atom, the energy gap of orbits: a) increase b) decrease c) remain constant d) first increase & then decrease	Energy gap between orbits	"*As E α n^2 energy gap increases as distance of electron increases".* *"Orbitals are elliptical in shape and on moving away orbitals with lower energy are at periphery & energy gap between them increases".* *"Orbitals are fixed energy state in which electron revolve hence the gap remains constant".* *"Every orbital have same energy level".*
4	Valency of an atom in a compound is equal to: a) combining capacity of an atom b) total electrons in outer most shell c) not related to number of electrons present in shell	The concept of valency	**"***Valency of an atom is equal to how many electrons revolve in outermost shell".* *"Valency determines the number of electron present for bond formation".* *"According to VSEPR theory Valency of an atom is equal to*

	d) eight minus total number of electrons in the outermost shell		*outermost electron".*

Table 4 (continued below): Questions on atomic structure and prominent misconceptions/ misunderstandings

For Item 1, 54 % of the students did present correct descriptions, indicating a sound understanding of the Rutherford's atomic model, whereas 25 % of the responses showed either a partial understanding or specific misconception/ misunderstanding. One of the descriptions indicated that Rutherford's model was a justification for the Thomson's plum-pudding model, and it appears that the significance of Rutherford's work in the advancement of atomic model has not been internalized by students. In a similar question based on Bohr's atomic model (Item 2), about 64 % of the students exhibited some misconceptions regarding shape and size of the orbit. Some explanations indicated that every orbital has the same energy level, and the energy gap between two orbitals is constant. In item 3, 38 % of students' responses did indicate some misunderstandings/ misconception, notably: "*Orbitals are fixed energy state in which electron revolve hence the gap remains constant"*. Students had some idea that the force of attraction between the nucleus and electrons decreases as a function of distance of electrons from the nucleus.

Even though the concept of valency has been studied from secondary school, almost 50 % of the students were not able to describe the same correctly. Valency was perceived as the total number of electrons present in an atom, and some students tried to connect VSEPR theory and valency.

No.	**Item**	**Theme**	**Misconceptions/ misunderstandings identified**
5	Isotopes of an element have: a) the same physical properties b) different chemical properties c) different physical properties d) same physical and chemical properties	Interpretation of the term Isotope	"*Isotopes are species with same atomic number but different chemical properties".* *"Different chemical properties due to different shapes of atom".* *"Isotopes having same number of electron and proton hence same physical and chemical properties".*
6	The energy of an electron in a Hydrogen atom in its ground state depends on: a) principal quantum number b) principal and azimuthal quantum number	Energy of electron and quantum number	*"Azimuthal & magnetic quantum number gives orientation and energy of electron".* *"Energy of an electron not depends on principal quantum number".*

	c) principal and magnetic quantum number d) azimuthal and magnetic quantum number		
7	The chemical properties of an atom are controlled by: a) number of protons only b) both number of protons and neutrons c) atom as whole d) number of unpaired electrons in outermost shell	Chemical properties of an atom	*"A chemical property of an atom is affected by Mass number of an atom"* *"Chemical properties are controlled by number of proton and neutron not by atom as whole".* *"Chemical properties of an atom is controlled by atom a (as) whole"*
8	According to Bohr's atomic model, energy of of an electron is given by $E = -13.6 \times (Z^2/n^2)$ ev. The negative sign in the equation indicates: a) decrease in energy of electron b) evolution of energy in the interaction of nucleus and electron c) absolute energy of electron d) potential energy of electron	Bohr's atomic model- energy of an electron in stationary state	*"Electron is revolving and while revolving lose some energy".* *"Negative sign in the equation indicate absolute energy of an electron".* *"Energy decreases due to increase of potential energy".*

Table 4: Questions on atomic structure and prominent misconceptions/ misunderstandings

For the question on isotopes (Item 5), one of the interpretations was that isotopes have different chemical properties, and some students also believed that chemical properties are due to different shapes of isotope atoms. In Item 6, related to the energy of the electron in hydrogen electron, 40 % of the students did not know of the correlation between energy and principal quantum number.

In the question related to chemical properties of an atom (item 7), almost 67 % of the students believed that chemical properties of an atom are related to unpaired electrons present in the outermost shell. For Item 8, which pertained to the energy of an electron in Bohr's model, a significant number of students' explanations (10 %) were categorized as partial understanding. These students believed that as n increases, Z increases and so the value of E increases. The negative sign was allocated to potential energy of the electron and they also perceived that the same indicates that the electron is stable by 40 % of the students, whereas another 13 % believed that the energy of an electron must be negative because of the negative charge of the electron.

Conclusions

Overall, students' explanations in this exploratory study indicate their poor understanding of atomic structure. The misunderstandings/ misconceptions are related to interpretations of different models proposed in the historical evolution of the understanding of atomic structure and electronic configuration. It is important to interview some of these students in-depth to obtain deeper insights about their thinking. Some of the written responses also indicated that language is an issue. Subsequent to this study, a detailed discussion with the chemistry faculty responsible for the content courses was conducted to sensitize them.

Acknowledgements

The author wishes to thank the Principal, Regional Institute of Education, Ajmer for providing an opportunity to do the research work for the study and Prof. Asha K.V.D. Kamath for her support in preparing the report for the study. He is also thankful to NCERT for extending funding and all facilities in the institute to make the present research study possible.

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AN EMPIRICAL STUDY TO EVALUATE UNDERGRADUATE STUDENTS' UNDERSTANDING OF STERILIZATION AND DISINFECTION

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As part of a larger project which aims to investigate the level of conceptual understanding in biology among college students and develop a meaningful pedagogy, we conducted a baseline test with 252 students enrolled in second year Bachelor's programme in Biotechnology or Microbiology, of four reputable colleges in and around Mumbai. We present here an analysis of three questions on methods of disinfection and sterilization, topics extensively covered in both theory and practicals as per the University curriculum. Analysis of students' responses revealed surprising gaps in understanding, which were poorly correlated with their academic achievement, and pointed to underlying lacunae in the teaching-learning process. Our observations could provide useful inputs for bringing about changes in the teaching learning process in introductory biology courses.

Introduction

Most science education reforms around the world have been centred around encouraging conceptual understanding among students (AAAS, 2001; NRC, 2012). The nature of incorrect ideas presented by students can provide insights into formative steps of knowledge construction by students and serve as feedback for improving the learning process (diSessa & Sherin, 1998; Tanner & Allen, 2005). It is thus important to identify and analyse students' understanding and determine the origin and structure of these diverse ideas. In the past decade, several reports have summarized the state of higher education in India and emphasized the need for major reforms at both structural and functional levels (UGC, 2016; Department of Higher Education, 2015; Nityananda, 2017). However, for initiating meaningful changes in higher education in India, this discourse needs to be substantiated with empirical studies. For instance, Phadnis and Pandit (2011) studied the role of conventional assessment methods in pushing students towards 'rote' learning.

Towards this effort, we designed a baseline study for second year students enrolled for the Bachelor's programme of Mumbai University in either Biotechnology (BT) or Microbiology (MB) to test their understanding of some foundational topics in biology. Both these programmes have been pitched as applied courses with placement prospects in industries and are popular choices amongst students. In this article, we present an analysis of three application based questions on methods of disinfection and sterilization, which are covered extensively both in theory and practicals in the first year (University of Mumbai, 2016). These topics are not only important as base concepts with applications in research/industry but are also relevant in real life situations. The questions tested students' application of these concepts in solving problems situated in real world scenarios. We believe that the results of this study may be useful for developing a concept inventory, and thus lead to an understanding of the issues in teaching learning of these topics.

Methods

Questionnaire design

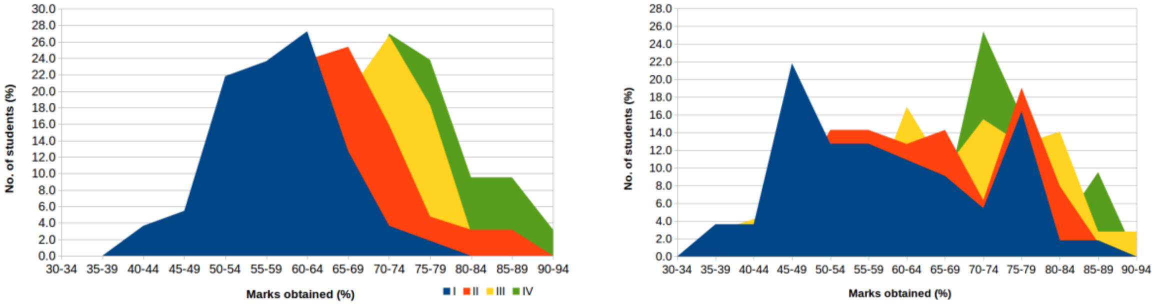
The questionnaire included both open-ended and multiple choice questions which required students to justify their choice. It consisted of questions from topics covered in their syllabus before they reached the 2nd year of B.Sc and were common to both courses. Care was taken that the topics chosen would not be taught anytime before or during our study. The questionnaire had nine questions; the time allotted was one hour. Three questions were designed for each topic - one each of ‘easy’, ‘moderate’, and ‘difficult’ level; the researchers assigned the difficulty level. The questions were designed to cover more than one concept and were multidisciplinary in nature. None of the questions was based on mere recall. A scoring scheme was prepared simultaneously which helped in the grading process later. An expert validated the questionnaire, its difficulty level, and the scoring scheme.

Participant selection

The baseline test was administered to 252 students - BT (100) and MB (152) from four colleges. These colleges were selected because they spanned a range of minimum eligibility scores required for admission to the B.Sc. programme (~50 % - 82 % aggregate score in Grade 12). The Grade 12 scores are based on a common countrywide examination and are crucial for securing admission to the undergraduate programme.

College			**I**	**II**	**III**	**IV**
Minimum eligibility score (%)			42	54-56	70	82
Total no. of students	**MB**	Male	34	22	33	31
		Female	8	6	5	6
	BT	Male	10	21	30	22
		Female	3	7	3	4

Table 1: Stated minimum eligibility score and no. of students from each college



(a) (b)

Figure 1: Distribution of students' marks (a) in Grade 12 (b) in the first year (MB/BT)

Copies of students' mark sheets (Grade 10, 12 and the first year of B.Sc.) were obtained from them; the minimum eligibility score for entrance was obtained from the college authorities. The distribution of participants' Grade 12 and the first-year marks (in their discipline – MB or BT) is shown in figures 1(a) and (b) respectively. Students in their second year of B.Sc. are typically between 19-21 years of age.

Data collection and analysis

The questionnaire was first administered to college II, followed by the other three colleges spanning a period of four months as per time slots provided by the college. The researchers in alignment scored responses from college II to the questionnaire independently with the scoring scheme prepared earlier. Minor discrepancies (<0.5 %) were resolved through discussions among the researchers and the expert. After grading these papers, preliminary categories emerged, which were refined through iteration and a coding scheme finalised in discussions with the expert. The questionnaire was then administered to the other three colleges.

Results & Discussion

Correlation between academic performance and baseline test marks

A correlation analysis was performed between first year MB/BT scores and those obtained in the baseline test conducted by us, using Libre-Office Calc. The correlation coefficient (R) was found to be 0.35, indicating a weak correlation between their academic performance (first year) and the baseline test marks for sterilization. The results are presented in a correlation plot (figure 2) with a determination coefficient (R^2) of 0.119.

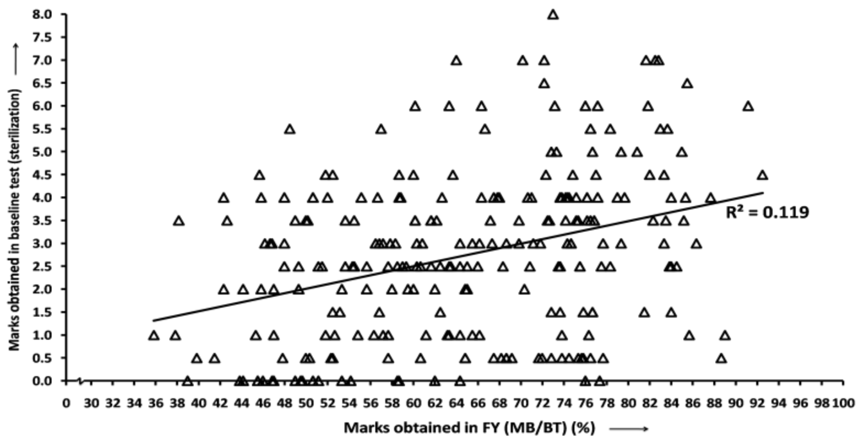


Figure 2: Correlation between academic (first year) scores and baseline score (sterilization)

Responses – based on principles or buzzwords?

The first question, marked 'easy', was:

Q. A researcher needs to sterilize the following items: (a) A solution of vitamins, (b) contaminated hospital linen (c) petri dishes. Which method(s) will you suggest for each? Give reasons for the method(s) you have chosen.

This question aimed at testing students' ability to link a method to its principle/mode of action and thus decide which method would be appropriate for the sterilization of some commonly used laboratory material. Each of the sub-parts were marked and categorised separately. The categories that emerged after assessing student responses and the percentage of students in each category are shown in figure 3.

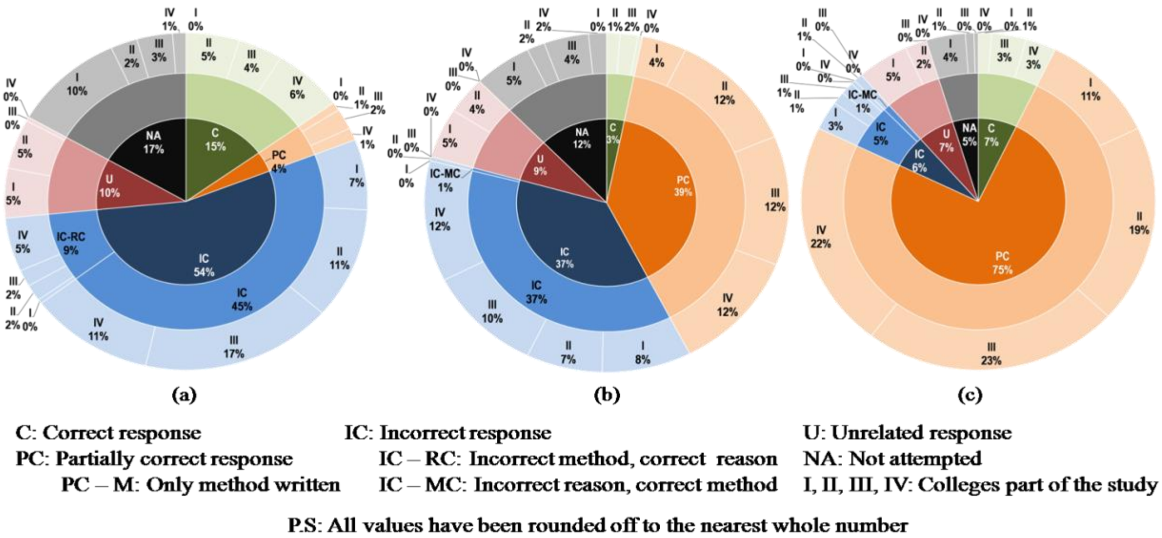


Figure 3: Percentage of student responses in each category (a) Vitamin solution (b) Contaminated hospital linen (c) Petri dishes

Around 15 % of the students gave a correct response for sterilization of vitamin solution. These students suggested filtration as the method for sterilizing vitamins citing heat lability of the solution as the reason. However, most of the students said that heat cannot be used because it would 'denature' vitamins. It is quite possible that the students associated the term 'heat labile' to 'denaturation' of proteins thus using the same term while describing another heat labile substance - vitamins. It would be interesting to investigate if the students assumed a structural similarity between the two biomolecules.

Of responses marked as incorrect, 45 % of respondents failed to acknowledge the heat labile nature of vitamins and suggested the use of hot air oven or an autoclave. It was intriguing to note that another 9 % of students who did recognize the heat labile nature of vitamins still proposed incorrect methods. Some advocated the use of autoclave or heating at lower temperatures (between 50-60 ^{o}C) instead of hot air oven at high temperatures (between 160-200 ^{o}C). Other suggestions included the use of Ultra Violet (UV) radiation, chemicals or centrifugation for sterilization of vitamins. Curiously, some students suggested the use of refrigeration as a technique for sterilising vitamins, perhaps confusing it with preservation.

While recommending a sterilization technique for contaminated hospital linen, only 3 % of students were able to suggest a correct method, acknowledging the nature of the material and the associated microbial load. A range of incorrect methods for sterilization of hospital linen were proposed by 37 % of respondents. Some students proposed the use of UV radiation or laminar flow, clearly not understanding that the entire surface area of the linen may not be exposed to UV light and the unsuitability of the method considering the bulk of the material. A few students mentioned that washing with detergents or disinfectant solution could be used to sterilize the hospital linen.

Only 7 % students gave a completely correct response for sterilizing petri dishes. A large number of students (75 %) recalled the correct method but failed to justify the answer and thus were marked as partially correct. The category of incorrect responses (6 %) included a variety of suggestions: use of disinfectants such as sodium hypochlorite, phenols, alcohol, using detergent for washing, boiling, keeping in incubator or increasing the pH.

In summary, students appear to be familiar with many methods used for sterilization but are only able to recall them as 'buzzwords' without actually understanding the principle of a technique and its appropriateness for the given situation. In addition, they have suggested methods which are most commonly used and associated with conspicuous equipment in an undergraduate laboratory i.e. autoclave, hot air oven and laminar air flow hoods. They seem to be unsure about methods such as membrane filtration which is not a common technique used by them for sterilization.

Biology vs Math: A familiar struggle

The second question, of 'moderate' difficulty level, was:

Q. A food preparer did not wash his hands and probably introduced 50 E.coli cells in the dish. E.coli doubles every 20 minutes and the dish has been kept outside for about 4 hours. If 200 cells degrade 1 gram of the dish, determine how many grams of the dish will be degraded at the end of 4 hours.

To answer this question student were required to calculate the microbial load in a dish after a period of time keeping in mind the exponential growth of the bacteria mentioned in the question.

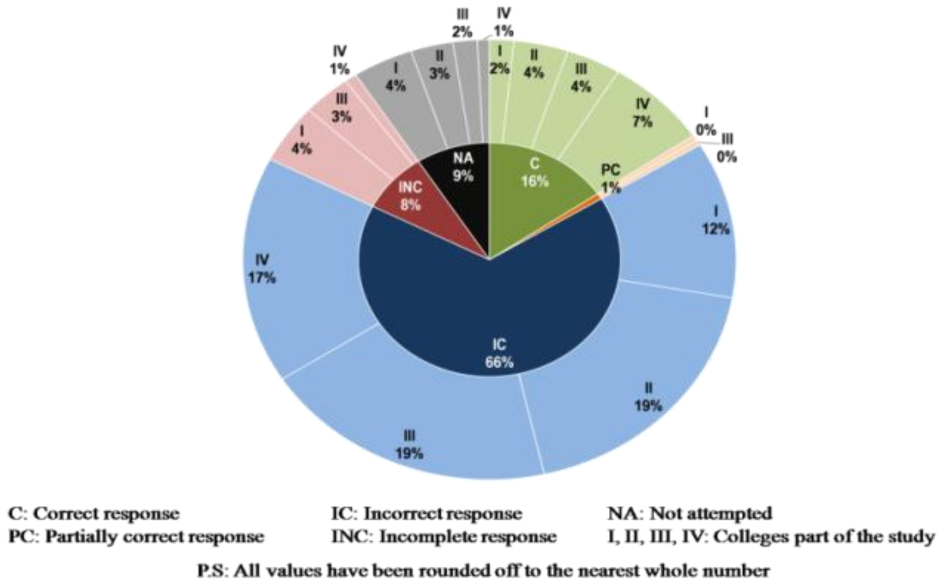


Figure 4: Percentage of student responses in each category

Analysis of student responses to this question gave us more insights into the content errors that these students harbour (figure 4). A staggering 66 % of responses were incorrect while only 16 % were correct. This question required basic quantitative skills; besides, students were expected to have solved such questions while learning the topic of ‘growth curve' – that is dealt with in detail, both during the practicals (5 three – hour sessions), and theory (15 lectures of 50 minutes each). Many students (22 % of the incorrect responses) have considered the growth of the organism to be linear rather than exponential: they have simply multiplied the number of generations with the initial no. of cells to get the final no. of cells in the dish.

Across colleges, a similar percentage of responses were incorrect (I - 12 %, II - 19 %, III - 19 %, IV - 17 %). This indicates that there is a widespread problem with solving a mathematical question, irrespective of the way the topic may have been taught. Sizable fractions of students (20 %) have made simple calculation errors. Disturbingly, students had difficulties with basic mathematical operations, viz. multiplication and division.

Disinfection *vs* Sterilization

The third question categorised as ‘difficult’ was:

Q. Give your comments on the following: A doctor has just finished removing a patient's infected kidney and is hurriedly moving to treat another patient who has suffered from burns. So he quickly wipes all his instruments with a cotton swab dipped in phenol and proceeds to wash them with soap water, then treats the patient who has burns.

The question was designed to reveal students’ understanding about the differences between cleaning, disinfection, and sterilization processes. Students had to recognise that a patient suffering from burns would stand a greater chance of getting infected and then judge the procedure followed by the doctor.

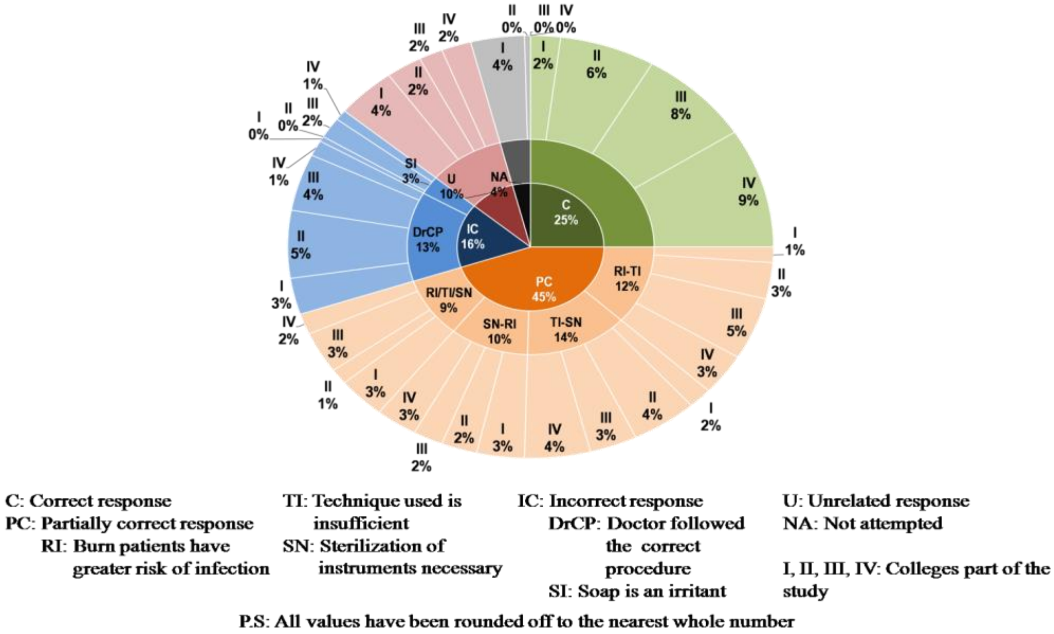


Figure 5: Percentage of student responses in each category

As shown in figure 5, only 25 % of the total responses were completely correct. These students made comments on the insufficient procedure followed by the doctor, as well as on the risk of transmission of infection from the infected kidney to the burns patient. They also mentioned the correct sterilization procedure. Another 45 % of the respondents were able to list any two, or at least one, of the aforementioned procedural flaws.

A matter of concern is that many students (16 %) have written a completely incorrect response. Of these, 13 % students wrote that the doctor actually followed the correct procedure, although the doctor had only disinfected the instruments and not sterilized them. A smaller fraction of students (3 %) commented only on the use of soap saying that it should not have been used, as it is an 'irritant'.

An understanding of the difference between sterilization and disinfection is crucial for students of both courses as most of their experimental results hinge on the level of sterilization and disinfection in the laboratory. Yet many students were unable to distinguish between the two.

Strengths and limitations of the study

Although relatively small in scale (one University, four colleges), the results highlight the importance of rooting curricular and pedagogical reforms in empirical studies. We could unearth a range of lacunae in students' understanding of the chosen topic with just three questions. One limitation of the study was that we could not administer the pilot due to scheduling constraints of the colleges. However, no new categories had to be added to those formed for College II to accommodate responses from the other three colleges, indicating the robustness of the test.

Concluding remarks

Students' performance in the baseline test was found to be poorly correlated with academic achievement implying underlying issues with the teaching learning and assessment process. Students' suggestions of using disinfectants for sterilization indicates either a lack of understanding of principles or a confusion in terminology for two very distinct processes. This is concerning because such basic knowledge is expected of a scientifically informed population and particularly so because many of these students do go on to find placements in the public healthcare industry.

It is evident from the results that even though students are taught methods of sterilization in detail, both in theory and practical sessions, a clear disconnect between theory and practice was apparent in their responses. The practical classes are typically structured to accommodate a large number of students following 'cookbook' protocols to achieve a defined objective in a given duration of time. They are neither accommodative of negative results nor do they allow for hypothesis testing but merely serve as validation routines. The theory and practical sessions are also scored separately in the University exams creating a further disconnect. Such a segregation of theory classes from practical sessions often leads to students' lack of conceptual clarity (Abrahams & Millar, 2008). Another area of concern is the dismal performance in the problem requiring quantitative reasoning; indeed biology students' problems with mathematics are well documented. It is widely acknowledged that basic mathematical skills are not only essential for a career in research but also for making intelligent decisions as citizens (Herreid, 2014). There has been increasing evidence that teaching mathematics to biology majors in the context of biological problems enhances their mathematical skills (Bialek & Botstein, 2004). Simple exercises in the biology lab could be used to generate data which can be examined and discussed in theory classes.

An ideal constructivist approach would be to intercalate theoretical concepts with laboratory-based activities and inculcate problem solving skills (Kloser et al., 2011). Eg. One can get students to question and test why only some methods of sterilization are suitable (for a given material) while others are not or whether a particular method followed in lab for sterilization, say for growth medium, actually resulted in complete sterilization. Also the growth curve is invariably represented with *E.coli* cultures with a doubling time of 20 minutes, almost used as a 'Universal Constant'. Instead, one could easily vary the growth conditions in the lab and actually test the doubling time or test different disinfectants for their effectiveness by coupling the activity with plotting of growth curve and calculations for residual bacterial load.

We believe that the findings from the study would be useful for both curriculum designers and in-service teachers. It has given insights into lacunae in students' understanding and pointed to easily doable changes in the curriculum. We hope this demonstrates the need for meaningful reforms in higher education driven by focused discipline based education research.

Acknowledgements

We gratefully acknowledge the co-operation of the participant colleges and students.

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PROBING STUDENTS' CONCEPTUALISATION OF HUMAN DIGESTIVE SYSTEM USING A DRAWINGS BASED TASK

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Drawings are considered a significant cognitive medium to express and represent ideas as internal representations (or mental models) by augmenting memory and information processing. This paper explores school students' thinking, and visuospatial modelling around human digestive system (HDS) through their drawings. The paper attempts to provide evidences for students' use of mental modelling in expressing conceptual understanding. Two parallel forms of a drawings based task were administered on a sample of 672 students from grades V to IX representing two schools affiliated to National and State board, located in Hyderabad city. The study reveals some interesting points about students' representations related to the alimentary canal, specificity of organs an spatial relationships between organs. The paper draws attention to the need for strengthening visualisation and modelling experiences to address the gap between students' mental modelling and their conceptual modelling.

Motivation and context of the study

School science education aims at developing scientific literacy and thinking skills (Gilbert, 2005). Visualisation plays a significant role in dealing with the abstract (invisible to naked eyes) and complex (specific understanding derived from structure-function relationship in an integrated manner) concepts. Human digestive system (HDS) is one of the foundational systems concepts introduced in school education in various ways in different textbooks. While some emphasise the introduction of 'food' aspect (colour, taste, utility for body, etc.), health concerns (digestive disorders as constipation, diarrhoea, etc.), others focus on the 'static and dynamic' aspects (structure-function of digestive organs, processes, inter-relationship within the system as well as with other systems like respiratory system, circulatory system, nervous system, etc.). The complex nature of HDS seeks students to not only visualise the abstract, static structure of its organ constituents, but also requires an integrated understanding of dynamic aspects. Literature suggests that drawings play a significant role in understanding student's ideas and knowledge about scientific phenomenon, particularly HDS. Several studies (Cakici, 2005; Teixeira, 2000) used drawings to investigate what students perceive and think about HDS. Reiss et al (2002) in their cross-sectional study with 586 young students from 11 countries belonging to the age group of 7-15 years used drawings to probe what they think of what is inside them. They found that students had a broad knowledge of organs and their internal structure. However, they had little understanding of an integrated system. By using two tools: a human biology knowledge questionnaire (HBKQ), and drawings, Prokop & Fancovicova (2006) examined teacher-students' knowledge about the human body. The study involved 133 first year university students in the age group of 18-23 years. The results suggested that students faced problems in understanding digestive system (nutrition processes) as distinct from other body systems, such as respiratory and the endocrine system. The students often confused the concept of 'location' as 'independent from function'. On several counts, the knowledge of adult students was inconsistent.

In the Indian context, Mathai & Ramadas (2009) explored the role of text and drawings while probing middle school students' understanding and visualisation of human body system. They gave written questions about digestive and respiratory systems to a sample of 87 students from Grade 8. They found that students better expressed their understanding of structure-function through text. Students' drawings were 'imperfect copies' of canonical textbook diagrams of digestive system. Similar ideas also reported in a Turkish study, where Cardak (2015) explored 116 student science teachers' understanding of digestive system through their drawings. He found that a few students had misconceptions like no structural relationship between organs, 'system' implied an open-ended structure through which oral nutrients arrive to the stomach. Carvalho et al (2004) suggested that students hold a range of 'epistemologically rooted misconceptions' regarding structure-function linkages, system understanding restricted to a particular organ (stomach), etc. across the grades and cultures. In order to address this range of conceptions among learners, modelling and simulations are considered to be core competence (Gobert & Pallant, 2004).

In this study, term 'model' refers to 'internal representations of any event, phenomenon, concept, or process' (Gilbert, 2004). Internal representation requires students' ability to visualise, assess all components, their relationship, and their functional purposes in an integrated manner. Students' drawings not only depict their conceptions but also provide leads into the obstacles they face in grasping and articulating their ideas. Scherz & Oren (2006) suggest that in biology, examinations are mostly based on factual knowledge and less emphasis is being given to rational thinking, problem solving, and decision-making approaches. In order to assess students' conceptual understanding, reasoning, and mental processing, either text or drawings alone cannot be sufficient. We need to develop an integrated tool that would help us in exploring and understanding the nature of thinking, expression and understanding (component/integrated form). Taking cognisance of these ideas, we develop a drawings based task that not only required students to visualise and draw but also encouraged them to write about the sites (organs) and processes (change in cake).

Study objectives

The larger study explores school students' use of visuospatial modelling in conceptualising HDS. As a part of this larger study, we analysed National and Telangana State Environmental Science and Science textbooks to see the treatment of HDS and its progression across the grades. Since drawings, based task is an open-ended one and dealt within textbooks, it can have appeal to students across all grades (Singh, 2017). The core objective of this paper is to probe students' thinking by using a drawings based task to explore their use of visuospatial modelling in articulating their understanding of HDS. This understanding will enable us to relate to the mental modelling associated with an invisible, routine, digestive process and explore the nature of obstacles students tend to find in visualising and processing the concept.

Methodology

A cross-sectional study was designed to explore middle school students' conceptualisation of HDS by assessing their responses on a drawings based task. Two equivalent forms of the task (Form A and Form B) were developed and administered seeking students' mental processing regarding food (cake) flow in body. This depiction seems to reveal nature of possible organs, structure, shape, position, and other structural relationships of organs in body viscera. Both content validated forms had a common question:

'*Imagine that you are eating a big cake of your most favourite flavour (write the name of flavour). In the visual of the human digestive system, label each organ in the box provided. Using arrowed lines (→ → →), show the path the food (cake) takes as it travels through the body. On the next page, is a table where you could write what would happen to cake as it passes through every organ and how it would look then?*'

Though both forms sought students to trace the cake's path, they differed in terms of providing cues for students. Figure 1 provides a glimpse of the visual used in both forms of task. While Form A (administered on section A) had a representation of organ structures in human body as cue to trace the food movement inside the body. Form B (administered on section B) only had body outline encouraging students to represent organs as well as food path. A total of 672 (age group 8-17 years) students from two sections (A and B) of each grade V to IX in two schools, one affiliated to National board (Central Board of Secondary Education) and other to State board (Telangana) were selected purposively (Refer Table 1). The sample was taken from these grades because HDS is dealt in grades V to VII. While grades VIII and IX were taken to get a sense of general pattern and see if there is an increasing detail in their drawings. The explicit focus was on exploring and understanding the nature of students' understanding, how they perceive HDS rather than assessing the extent of their knowledge of HDS. We did not include class X because of a few constraints as accessibility, complexity of treatment, etc. We wanted to see how the same questions are being responded by students across grades differently. Though the sample was drawn from two different boards, this study does not make any explicit efforts to derive a comparative analysis or use it for studying gender differences in students' responses. Also anatomy and digestion process at biochemical level (role of enzymes) is not a focus, largely because these dimensions in digestion are covered in higher grades.

Grade	No. of students	Percentage
V	189	28
VI	115	17
VII	122	18
VIII	178	27
IX	68	10
Total	**672**	**100**

Table 1: Composition of sample

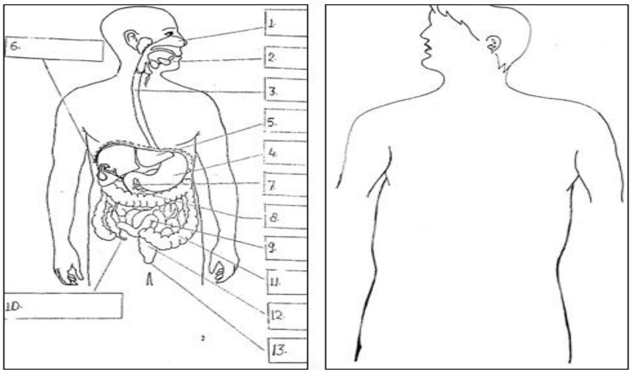

Figure 1: Images used in Form A (with cues) and Form B (no cues)

Analysis and insights

The drawings and responses of students were analysed for patterns of responses and were categorised to draw analytical insights about students' conceptions. This paper does not discuss derived themes. It is based on insights gained from analysis of drawings based task. Table 2 provides an overview of all observed categories with percentage of falling instances.

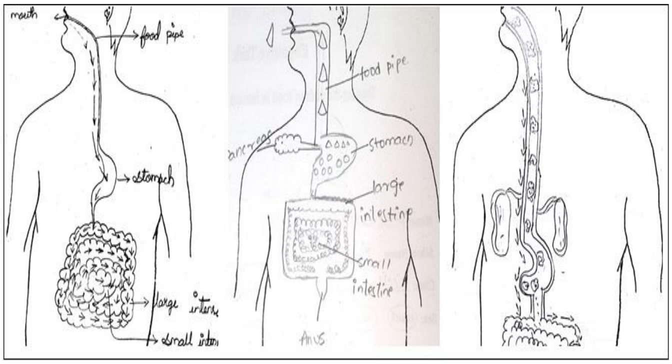

Figure 2: Concrete vs. Abstract vs. Mixed

The categories such as abstract vs. concrete, aesthetic vs. conceptual preferences, and systems vs. components are binary in nature. Here, concrete vs. abstract refers to nature of representation of cake (food flow represented through arrows or food flow as site-specific breakdown or mixed showing both (7 %) (Refer Figure 2), system vs. component refers to depiction of organs drawn (holistic or part), and aesthetic vs. conceptual preferences refers to students' preferences and focus on drawings (completion and detailing of body outline or system organs). The students falling in category aesthetic also drew elements of HDS. Form B students showed more abstract (12 %) and concrete representation (22 %) than Form A (8 %). It suggests open-ended form enables students to explore more about food path. These binary categories enabled us in exploring their preferences and general pattern of a particular age group especially Form B. For instance, one-fourth students (mostly from class V, VII) showed an artistic tendency to complete outline by adding body features e.g. nose, ears, hair, legs, etc. They also drew cake (a piece, multi-storey) with a (burning) candle.

S. No.	Categories	Form A (%)	Form B (%)
1.	Concrete vs. Abstract vs. Mixed	8/0/1	22/12/11
2.	System vs. Component	NA	14/86
3.	Aesthetic vs. Conceptual preference	NA	28/72
4.	GIT-Open-ended continuous	NA	60
5.	GIT-Closed	5	23
6.	GIT-Ending in stomach	NA	8
7.	Path of food (cake)	22	51
8.	Continuity between organs	22	15

9.	(Mis)Order of digestive organs	3	7
10.	Other organs representation	90	39
11.	Representing major digestive organs	95	48
12.	Relative position of organs	NA	8
13.	(Mis)Identification and labelling	90	15
14.	Specific structure of organs	NA	88
15.	Digestion process (change in cake)	15	23
16.	Drawing of a fancy cake and candle	0	9

*NA-Not applicable.

Table 2: Categories of students' responses

Students’ drawings of Form B were categorised as realistic (canonical) (82 %), mixed (10 %), and schematic (8 %) representation (refer Figure 3). A realistic image includes diagrammatic representation of organ systems, which is equivalent to exactly real HDS; schematic one includes representation of elements of HDS through abstract, graphic symbols, while mixed representation includes both realistic and schematic representation.

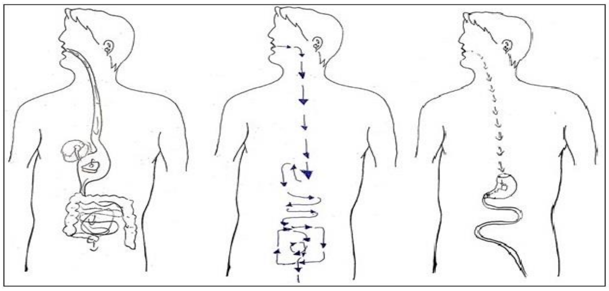

Figure 3: Students' drawings (realistic, schematic, mixed)

Interestingly, the number of schematic representations was more in lower grades (80 %) than higher grades. This could be due to their exposure to textbooks which have some schematic visuals (Telangana Board, Grade V).

Apart from the above observation, a few critical insights can be drawn from study. An effort is made to capture the findings in a coherent manner in the following sections:

Struggles in visualising and representing organs with respect to body

Both forms posed certain limitations in students' natural responses. For instance; availability of cues limits scope of visualisation, it may also enhance interference by other organs. We found that 90 % of Form A respondents mislabelled digestive organs by other organs (e.g. heart, ribs, nerves, kidney, trachea, thyroid glands, urethra, penis, cerebrum, ovary, etc.). A few of higher students depicted male (testis) and female (ovary) reproductive organs in the given human viscera (Figure 4). This suggests that students have vague understanding of organs and their functions. Textbooks analysis suggests that students at higher grades (IX onwards) are exposed to new information; anatomical and biochemical level e.g. structure-function of cell, tissues, content elaboration of HDS i.e. peristalsis in oesophagus/

stomach; role of enzymes, and detailing of other biological systems). This new knowledge of other systems (respiratory, excretory, and reproductive) also seems to interfere with their knowledge of digestive organs particularly in later grades as we noticed students from grade IX struggled in identifying lower digestive organs (particularly rectum, colon, and anus) and mislabelled them with reproductive organs (penis, testis, vagina, ovary). Similar idea is also noticed in students' difficulty in differentiating wind pipe and food pipe. This suggests that parallel/superimposed position, complex arrangement, and weak understanding of relative positions of organs such as excretory (urethra, urinary bladder)/reproductive organs (penis) and digestive organ (anal), pose difficulty for students to differentiate organs. This interference is more evident in Form A.

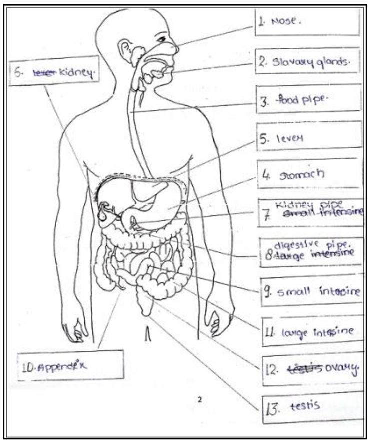

Figure 4: Reproductive organs

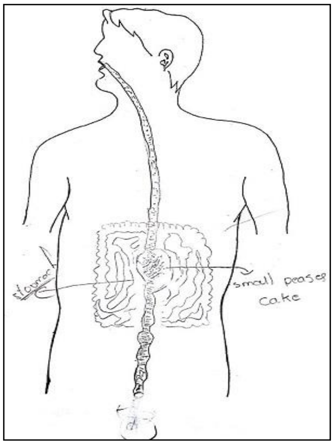

Figure 5: Relative position

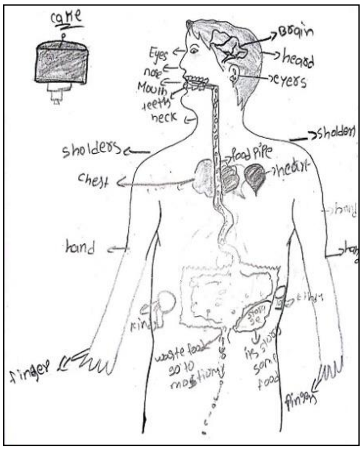

Figure 6: Interference of organs

Students faced difficulty in replicating their ideas of three-dimensional visualisation on a two-dimensional medium (here A4 size paper). Students' drawings showing relative positions of organs (Figure 5), interference of organs (ribs, chest, Figure 6) suggests that students faced difficulty in representing their understanding of location, position, and organisation of different organs within the body. The constitution of different systems within a body is a complex idea. Textbooks use two-dimensional images to represent this complex organisation, which pose difficulty to students to replicate it on paper due to lack of sufficient understanding and visualisation. Representation of a less known abstract concept seems a quite difficult task for learners. Visuals and content prescribed in textbooks seem to make them able to visualise structural relationships among organs up to some extent. Most of the Form B respondents adequately drew digestive system up to intestinal part but none of them differentiate and label colon sub-parts. It suggests that complexity of the system (compartmentalisation and convolution) restricts their visualisation further. This difficulty can also be traced in visualising junctions between organs, even when cues are given. For instance, 18 % of Form A respondents faced difficulty in showing food flow after duodenum as large intestine covers major portion of duodenum. Similar incident can also be noticed at small intestine-large intestine linkage and oesophagus-stomach linkage. A few of students showed various paths of cake e.g. [oesophagus→ liver→ stomach →large intestine], [oesophagus→ stomach→ large intestine], [oesophagus→ body viscera→ colon, etc.]. This suggests superimposed nature of organs poses serious difficulty in conceptualising continuity of system. This incomplete visualisation and modelling may cause a deviation from conceptual understanding.

Segregated understanding of a systems concept

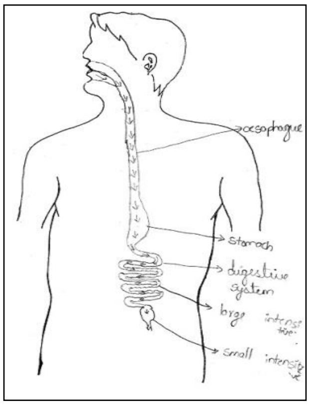

Figure 7: Order of organs

A system understanding seeks integration of all its constituents and its significance for body. Students' systems concepts understanding is limited to a few major and popular organs. Oesophagus, stomach, and intestinal part were frequently drawn and identified organs followed by liver. Students also showed some structure-function related alternative conceptions (refer Figure 5). For instance, structure of small intestine and large intestine (both depicted as a long tube), structure of stomach (square, box shaped), relative positions of organs (stomach surrounded by small intestine and large intestine), order of organs (intestine ending in stomach, large intestine followed by small intestine, refer Figure 7, liver opens in stomach), connection between organs (intestine an independent coiled structure having no connection with stomach, stomach connected to large intestine), organ within organ (heart in lungs). Students from early grades (V, VI, and VII) adequately drew and labelled digestive organs than higher grades (VIII, and IX). Analysis of Science textbooks revealed that students at early grades have more conceptual and visual exposure than later grades (VIII, IX). This could be a possible factor for their adequate representations. The early content exposure, relatively larger size, emphasis over major organs in textbooks, etc. seems to be easily accessible by students. Almost 48 % students identified major organs though they were unclear about their functional utility for body. About 40 % (mostly VIII and IX) showed confusion between small intestine-large intestine and labelled them interchangeably. In Form B, about 40 % students drew a pipe-like structure to show intestinal parts (both small intestine and large intestine). Students' responses regarding accessory organs, their structures, shape, size, location and functions, etc. were least identified and elaborated (14 %), though large chunk came from Grade V (54 %). This might be due to their exposure to content delivered by National board textbooks, which offer them a wide exposure of HDS. This includes description and depiction of minor digestive organs in text and visuals. The analysis suggests that about 38 % students acknowledged the change in cake's shape and size. A couple of students also drew teeth (refer Figure 6) and mentioned chewing process (cake changes into powder in stomach, watery in large intestine, and solid in small intestine). They demonstrated varied understanding of digestion process. A few respondents mentioned that food changes into liquid completely and coming out as liquid from anus. This incidence may also get shaped by their experience of illness (e.g. loose motion). These responses are conceptually not correct but they showed a little understanding of breakdown of food inside the body. They showed limited understanding of nature of breakdown (solid, semi-solid, or liquid, and change in its shape) irrespective of its digestive site. For instance, there were a number of cases who drew even bigger cake of different shape (triangular, pentagonal, trapezium, etc.). It suggests that students faced difficulty in visualising-conceptualising site-specific change in food irrespective of their ability to visualise and represent cake flow in different organs.

Varied understanding of nature of gastrointestinal tract (GIT)

Nature of gastrointestinal tract (GIT) can be understood in terms of path of food in body. Analysis suggests that half of the Form B respondents (52 %) evidently showed path of food than Form A (30 %) despite of given instruction. On an average they have a varied understanding of nature of GIT ranges from continuous, closed (refer Figure 8) to ends into an organ (stomach). About 60 % of students have a general notion of GIT as an open-ended continuous tract. Continuous nature of GIT also tells about continuity (connection) between organs. About 13 % of total respondents showed misconnection between organs (largely small intestine-large intestine, stomach-small intestine); while more than one-fourth depicted no connection in between (e.g. oesophagus-stomach, stomach-small intestine, and small intestine-large intestine). The understanding of nature of continuity suggests integrated understanding of organs, order and their functions, and their utility for survival. About one-fourth considered it as a closed system (and/or ends in intestine). This assumption may lead to development of alternative conceptions such as food does not leave out and remains inside the body. About half of students across all grades think so. This observation has also been corroborated in another context in the study by Cardak (2015). Teixeira (2000) reported that nursery students have predominant idea that indigested food remains inside body, which gets modified into understanding of absorption of useful nutrients and removal of waste by age of ten years. Interestingly, we found it contrasting, students even in age group of 13-15 years, consider that food remains within body. A few students (8 %) depicted GIT ends in stomach which is evident in grade VI (38 %), and VII (24 %) students. This idea suggests that students do not conceptualise and articulate 'absorption' aspect. This may also gets influenced by general notion that whatever we eat gets stored in stomach.

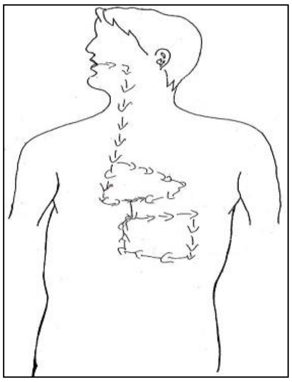

Figure 8: GIT- a closed system

Missing links between drawings and written responses

Students also had to write organ names and change in cake that would occur in particular organs. Students seemed to prefer drawings over writing (inconsistent with Mathai & Ramadas, 2009). About 50 % of students attempted to write down organ-specific change in cake but did not draw cake path. Nearly half of the students wrote organ names and did not write anything about the change occurring in cake. In Form A, students also showed a tendency to replicate the structure of organs from the given image in the table. A few of students wrote nose/nostril/respiratory tract as a part of HDS.

Conclusions and educational implications

Use of two forms enabled us explore different nature of students' responses like difficulty in visualising static-dynamic aspects, nature of conceptions (including alternative conceptions regarding structure-function linkages) among students, interference of organs, limitation of cues, etc. Based on knowledge content in textbooks, one anticipates richness and complexity over grades but we did not find so. Students' drawings accompanied by text (labelling, sites, events, processes) reveal a nuanced understanding of their conceptualisation and thinking. Here, it is evident that though students do model structure-function linkage, organisation of system, processes, etc., but faced some difficulty in visualising and modelling abstract ideas such as arrangement of systems in body viscera. It also suggests that students visualise organs, organ systems irrespective of its relation to body division. Students seem to possess limited understanding of systems restricted to a few organs might be due to their structural features (size, shape and orientation of organs). The definite organ shapes seem to make them feasible to grasp visuals and make connections. For instance; large organs with simple shape (e.g. oesophagus-tube like, stomach-sac like, intestine-coiled, and liver-bean shaped) were most identified and frequently drawn organs than other relatively smaller, covered by other organs, with complex nature (e.g. pancreas-leaf like, etc.). A few of drawings showed a replica of digestive system provided in textbooks. In textbooks, more emphasis is placed over the major organs. A few incidences showed that textbooks themselves have some visuals (digestive system along with respiratory system, different positions of stomach, etc.) which pose difficulty for students to differentiate among systems and understand their utility. It also reveals the nature of alternative conceptions (related to continuity, compartmentalisation of GIT, interference of organs, etc.) limitation of visualisation due to complex nature of various systems, their interrelationships, arrangement, and significance for body. In order to overcome these issues, we need to design textbooks providing with explicit opportunities for modelling (including texts probe visuals, and designing hands on activities), and contextualising representation (systems representation with respect to body, utility of each organ, system, extension of knowledge). This study opens up avenues for curriculum designers to look for opportunities that can enhance and promote students' thinking in authentic contexts (everyday, real-life, social contexts). This study also brings up the active role of teacher in encouraging students to model the process as well as outcomes in biological systems, which is somehow missing in current scenario as noticed in textbooks. The study makes a case for the need to use visualization and modelling for teaching and engaging students with abstract biological concepts which are in sync with textbook content, students' thinking and reasoning, and the agency of teacher in relating to the content and students.

Acknowledgements

I owe my sincere thanks to students for willingly participating in this study. I am grateful to Tata Institute of Social Sciences for providing all support. I owe a deep gratitude to Dr. Ritesh Khunyakari, Ms. Shikha Takker and Prof. Jayashree Ramadas for their timely suggestions.

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MISCONCEPTIONS IN ASTRONOMY PRESENT IN HIGH SCHOOL TEACHERS: A PILOT STUDY

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Misconceptions about astronomy are commonplace in students even after them having taken introductory astronomy courses. There are many reasons for this, but the possibility that the existence of these misconception could be due to the fact that the misconception may be passed down by the teacher-instructor is something that needs to be explored. With this in mind, the authors have prepared a questionnaire consisting of assertions whose truthfulness would be gauged by the teacher-instructors. The responses were tabulated and are discussed in this paper along with some of the possible reasons as to why the respondents gave those particular answers. It was concluded that high school teachers face serious skill deficit to impart correct astronomical knowledge to their students. This deficit is not only in terms of lack of information but also, more worryingly, inability / unwillingness to extend their knowledge to make logical inferences.

Motivation

Misconceptions about astronomy are found quite regularly amongst students both at the secondary and the undergraduate level. Several scholarly works (Hufnagel et al, 2001-2002; Zeilik et al, 1998), Bailey & Slater, 2003), books (Plait, 2002, Comins, 2001) and websites designed by outreach experts *(eg. newyorkscienceteacher.com, www.astronomy.org, www.scc.losrios.edu, solarsystem.nasa.gov)* provide an extended list of such misconceptions. Every seasoned astronomy educator would also be able to share anecdotes about typical misconceptions in basic astronomy. Most of these works focus on listing. There are a few which discuss the possible remedial measures (Subramaniam & Padalkar, 2009). However, there is not much existing literature on the inadequacy of teacher knowledge about application of basic astronomy in day-to-day life and how this impacts student's learning of the subject, especially at high school level.

At high school level, especially in the South-Asian school systems, teachers are perceived by the students as the definitive source of scientific information. Teachers and students gather astronomical information not just from the textbook but also from traditional sources like folk tales from elders and anecdotes about cultural practices. The students rely on teachers for verification of this information and teachers are expected to update their knowledge to appreciate scientific principles behind the astronomical practices in day-to-day life. If teachers lack adequate information or skills to process the available information, then they either cannot transmit these ideas to students or transmit these ideas in a flawed manner. We looked at teacher's knowledge base in connection with some day-to-day astronomical practices, through means of a survey. This survey had a wide scope and in the present paper, we restrict the discussion to identification of zodiacal and other constellations and apparent motion of stars.

Existing astronomy curricula in India and Sri Lanka

Astronomy as a school topic is taught in India at grade 5 (1 chapter) under the subject of environmental studies (NCERT Text Book Class V Environmental Science), in grade 6 (2 chapters) under the subject of geography (NCERT Text Book Class VI Geography) and in grade 8 (1 chapter) under the subject of science. The relevant topics covered include rotation and revolution of the earth, the phases of the moon, time of moonrise on different phases, concept of leap year, solstices and equinoxes, time zones, stars, the pole star, constellations, the solar system, planets, and other minor bodies in the solar system, satellites.

In Sri Lanka, astronomy as a subject has only 2 chapters devoted to it in the school syllabus, 1 chapter in class 8 under the subject of geography (Sri Lanka Class VIII Geography text book) and 1 chapter in class 9 under the subject of science (Sri Lanka Class IX Science text book). In terms of the topics covered under the Indian syllabus, the Sri Lankan syllabus skips the topics of phases of the moon, moon rise times and the concept of leap year. However, the Sri Lankan syllabus does cover the topics of Galaxies, the Milky Way, the ecliptic region, star maps, birth and death of stars, a brief introduction to the big bang theory, Galileo's contributions to astronomy and history of astronomy through the topic of historical world models.

As the coverage is vast, topics are covered superficially and several key ideas related to these topics are left out. For example, the textbooks mention that there should be an extra day in February, every 4 years, but does not mention the fact that centuries are to be considered leap years only when divisible by 400 (Gregorian correction). Similarly, the textbooks don't explicitly talk about geometry of eclipses or different sunrise points over the year or change in the length of shadow in a course of day or precession of the earth.

Description of survey

The survey was conducted in Mumbai over two sessions with two distinct groups. The sample consisted of a total of 47 individuals divided into two subsets. The first subset was made up of 30 Indian teachers hailing from different cities of India. There were 14 male teachers and 16 female teachers in this subset. All the teachers were working as science teachers at secondary level in a school group with a national presence. They were all nominated for in-service training at the institute of one of the authors. The average teaching experience for this group was about 23 years.

The second subset was a group of 17 teacher trainers from Sri Lanka, attending a training camp organized again at the same institute. The members of the group were selected by the Ministry of Education, Sri Lanka for advanced training. It consisted of 8 male and 9 female teacher trainers and all of them had a science background. The average work experience of these teacher trainers was about 15 years.

As both groups were pre-selected through some other process, we may call this as cluster sampling based on convenience. None of the members in either sample had prior astronomy training. However, all of them had prior experience in teaching astronomy units at the secondary level. Although these groups may not exactly be the most representative of the teacher populations in either country, the authors wished to explore possibility of significant difference in responses due to differing cultural and educational backgrounds. Thus, the two subgroups were analyzed separately.

Survey methodology

The questionnaire that was developed was broken into 5 parts with an average of 12 assertions per section. The Sections were: Calendars, Constellations and movement of stars, the sun and moon, Planets and finally Social beliefs about astronomy. As mentioned earlier, paper will be concentrating on the survey responses to the sections on constellations and movement of stars.

In the questionnaire, the Respondent would have to determine the truthfulness of the assertion using the 5 point Likert type scale. The responses that were available to the Respondents were: Definitely False, Probably False, Don't Know, Probably True and Definitely True. A total of 11 assertions were present in the sections that will be discussed in this paper. All the statements in the survey were either part of the high school astronomy curriculum outlined earlier or were logical extensions of the topics that were covered.

The analyses of these responses have revealed a lot about the overall knowledge of these teachers with regards to astronomy. We also get an insight about which type of misconceptions end up being passed down to the students. Another aspect of the questionnaire was that some assertions in each section were correlated with each other. A correct response to one assertion with the right reasoning would help the respondent to get the right response to other correlated assertions in the section. Again analyses of these pairs of statements have yielded interesting results. We identified 3 statements in this section as the ones specifically relevant to Indian cultural practices and as such the authors didn't expect to gather any relevant data from the subset of teachers from Sri Lanka. For purposes of discussion, the authors propose to call the Indian teachers group the IN group and the Sri Lankan teachers group the SL group.

Data representation

The representation of the responses will be via stacked bar charts for the individual questions and bubble charts for studying the responses for correlated questions. The colour scheme used for the individual questions can be read as follows: Green: correct response, Yellow: leaning to correct response with less confidence, Blue: respondent claimed to have no knowledge, Orange: respondent leaning to incorrect response and Red: respondent confidently chose incorrect response.

The authors have opted to use stacked percentage bar charts over pie charts because studies show that the human mind is more capable of estimating and comparing lengths than at comparing area as outlined in the study here (www.perceptualedge.com/articles/08-21-07.pdf)

For the bubble chart the colour scheme is as follows, Green: the respondent gave correct responses to both the correlated answers, Red: he/she chose one correct response and one incorrect response, Yellow: if both responses are incorrect, Blue: if both options selected were “Don’t Know”.

Discussion of teacher responses

Here we restrict our discussion and analysis to the assertions made in the section on Constellation and Movement on stars and the responses made to them. The first set of correlated assertions were related to Indian astronomy. The assertions with the expected response are listed below.

1. Nakshatras always belong to raashis.

For readers not familiar with Indian astronomy, *Nakshatra*s is a term used for 27 lunar asterisms, whereas *Raashi*s mean the 12 zodiacal constellations. This assertion is false. The *nakshatra*s *Mriga, Ardra, Ashleshaa, Hasta, Swati, Shravana, Dhanishta, Purva Bhadrapada* and *Uttara Bhadrapada* are not part of any zodiacal constellation.

2. Shapes of western zodiacs are same as Hindu raashis.

This assertion is true. The western zodiacal constellations and Hindu *raashi*s are identified with exactly the same stars and with same figures. It is believed that Indian astronomy adopted the idea of zodiacal constellations after coming in contact with Greek astronomers travelling with Alexander’s army.

3. Orion the hunter is also a hunter in the traditional Indian system.

This assertion is false. In Indian astronomy, stars of Orion are identified with a deer (*Mriga*) who has been attacked by *Vyadha*, i.e. hunter, (Sirius) and has an arrow sticking through him.

As such, the aim behind including these assertions was to test the familiarity of the respondents with traditional Indian astronomy. Also with regards to the truthfulness of the assertions, it was assumed that the SL subgroup would claim that they lacked the knowledge to respond to these assertions. The analysis of the results did throw up some interesting results as seen in Figures 1 to 3.

We see from Figures 1 and 3 that, no person from the SL group was able to ratify these assertions correctly. This is not unexpected as these teachers may not realize that Sinhala calendar is based on same principles as the Indian calendar. What was surprising was that the IN group too managed to get mostly wrong responses. The responses to the second assertion was surprising as more than 60% of the respondents managed to get the correct response with some degree of confidence. This percentage held even when we look at the IN and SL sub group. This could mean that they come across at least names of western as well as Indian zodiacal constellations and they understand that the meaning in both cases is the same (e.g. Leo is the lion also as per Indian name). On the other hand, first and third assertion required at least some first-hand experience of night sky observations, which they clearly lack.

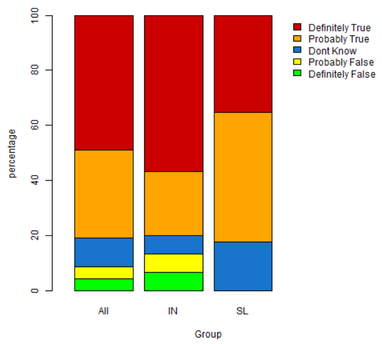

Figure 1

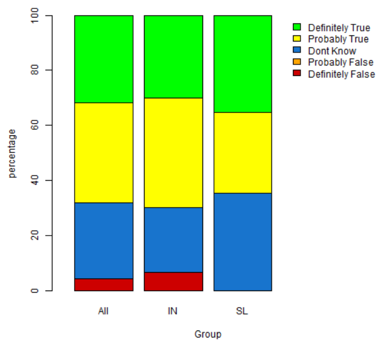

Figure 2

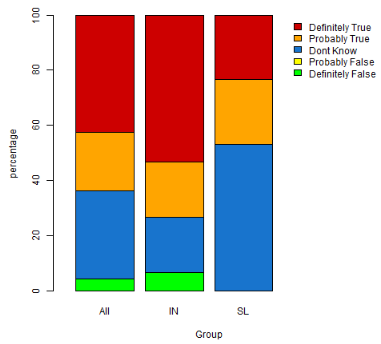

Figure 3

The second set of correlated assertions focused on the concept of spatial translation of the observer's frame. The assertions are listed below.

4. *Shapes of constellations would appear the same from any planet in the solar system.*

This assertion is true. The size of the solar system is miniscule as compared to distance to even the nearest star and so the location of the observer doesn't really change anything.

5. *Shapes of constellations would appear the same from any close by star.*

This assertion is false. The star nearest to the Sun is Alpha Centauri. If you travel to this star, then obviously the constellation of Centaurus cannot be the same, without its Alpha star and constellation of Cassiopeia will include an additional star, i.e. the Sun.

6. *The sun would appear to be in the same zodiac sign if observed simultaneously from different planets.*

This assertion is false. This would only be true for the only special case of the viewing planets being on the same side of the sun in line with it.

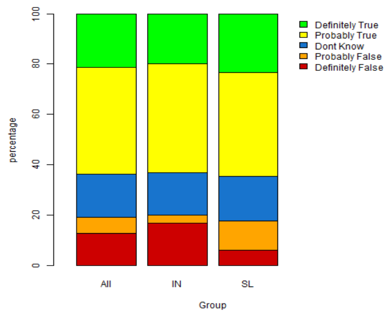

Figure 4

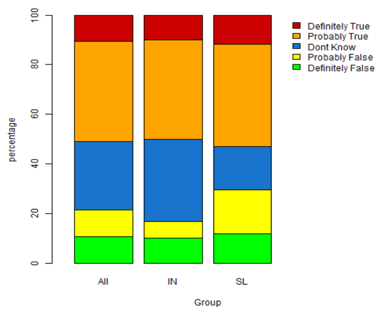

Figure 5

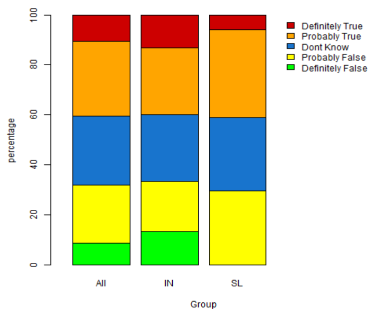

Figure 6

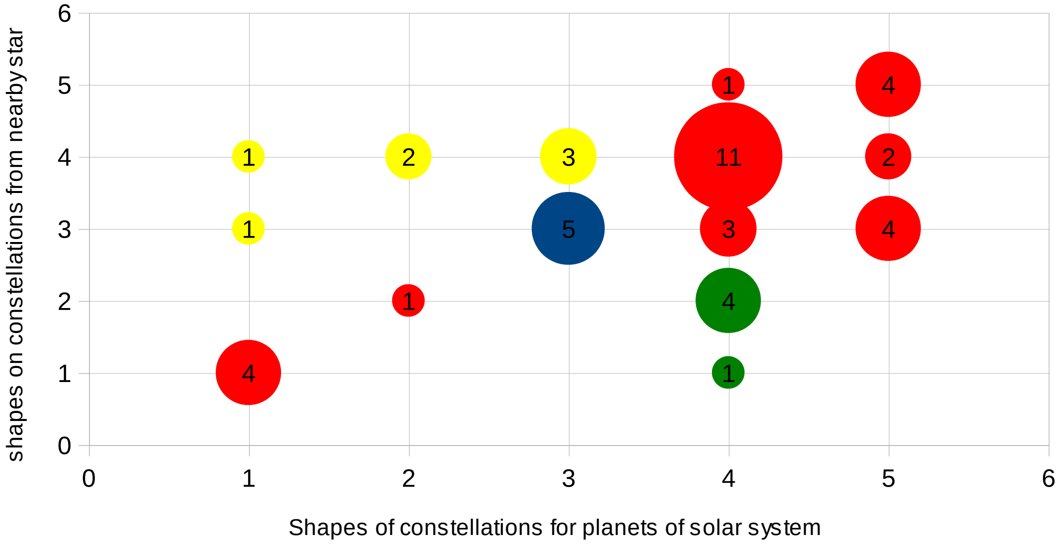

Figure 7

Here, the aim was to test the spatial reasoning skills of the respondents. The assertion 4, which was relatively simpler to argue for, was identified as true / probably true by more than 60% respondents from either groups. But they were unable to reason that the constellations would look different from nearby stars. This may either point to lack of spatial reasoning or unwillingness to employ it. The assertion 6 was in fact simpler to argue as compared to assertion 5, as many textbook diagrams and models of solar system in fact show planets in varied directions with respect to the Sun. However, we were surprised to see that the percentage of wrong responses is almost similar and there is not much difference in the two groups. Failure to reason this correctly may point to a possibility that the teachers don't possess correct mental model of passage of the Sun in different zodiacal constellations. They may be viewing it as an absolute phenomenon rather than an effect resulting from the observer's perspective.

A correlation analysis of the assertions concerning constellations viewed from the solar system and from a nearby star is displayed in Fig 7 and supports our hypothesis of teachers viewing it as an absolute phenomenon.

The third set of interconnected assertions focused on the respondents understanding of star motion as seen from earth at night. They are listed below as follows

7. All stars rise in the East and set in the West.

This assertion is false. For example, the North Star, Polaris, is nearly stationary in the sky.

8. Polaris approximately remains at the same place throughout the night.

This assertion is true. Since Polaris lies nearly along the axis of the earth, its position in the night sky doesn't change much.

9. Polaris is visible from all places on the Earth.

This assertion is false. Polaris is not visible from the southern hemisphere.

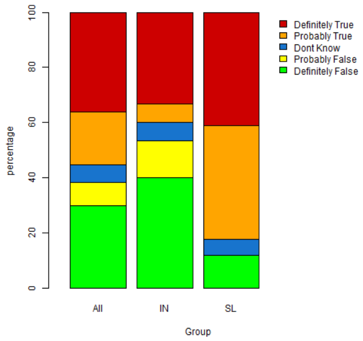

Figure 8

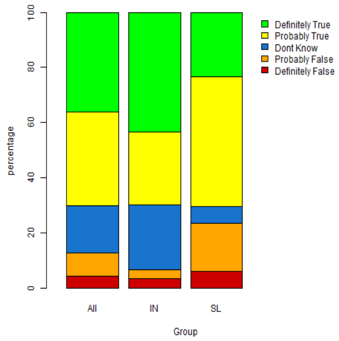

Figure 9

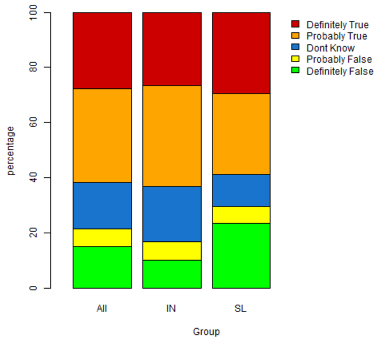

Figure 10

The aim behind these assertions was to gauge how well the respondents understand star position and star motion in the night sky. Assertions 7 and 8 were contradictory in nature and so it was expected that if someone had an idea about the night sky, they would see this contradiction and so answer both correctly. If someone got both assertions (star motion and Polaris's stationary position) wrong, we can conclude that the respondent doesn't have knowledge of one of the assertions and has misconceptions about the other and so has made an erroneous logical inference on the basis on what he/she thinks he/she knows. It's the respondents who have gotten one right and other wrong that turned out to have a large number. For these respondents, it is possible that they were either lacking knowledge about the assertions or were unable to see the logical link between the two assertions. In previous cases, we saw that teachers do possess information but do not extend or apply it to reach logical conclusion. Hence, it can be argued that same may be the case here.

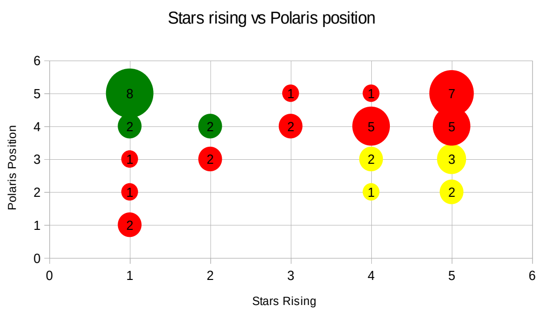

Figure 11

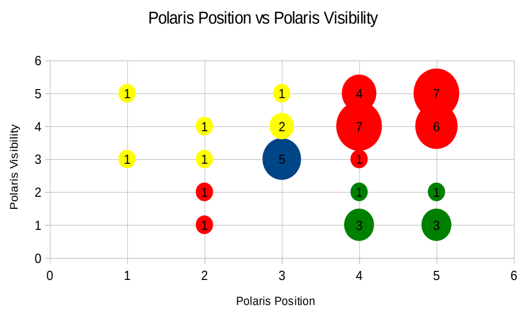

Figure 12

Summary

Looking at the overall responses to the survey and highlighted responses reported in the previous section, we conclude that high school teachers face serious skill deficit to impart correct astronomical knowledge to their students. This deficit is not only in terms of lack of information but also, more worryingly, inability / unwillingness to extend their knowledge to make logical inferences. Although this was a small sample, author's experience with other school teachers and anecdotal evidence gathered from other astronomy educators suggest that these errors are commonplace among teachers. Given this scenario on ground, there is added responsibility on textbook writers to make every connection more explicit. Alternatively, curriculum designers must create enough supplementary material for teacher use. This will assist teachers to shore up their knowledge and in turn help them to provide better scaffolding in the learning process.

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