Strengthening Teachers' Knowledge of Students' Conceptions in Physics

*Shruti Chopra**

Abstract

Understanding learners' constructs about various physical phenomena is an essential part of science teacher's knowledge of teaching. This study explores the entailments of strengthening physics teachers' knowledge of learners' conceptions regarding Thermodynamics and Kinetic Theory of Gases by engaging them in collective reflection on their classroom processes and students' thinking. It was found that despite several years of experience of teaching, the teachers lacked a comprehensive understanding of learners' alternative conceptions, learning difficulties and pedagogical strategies to address students' ideas. The goal of the study was to develop a model for teacher learning through a research-based, content-specific approach to promote teaching practices that is more responsive to developing students' understanding.

Key words: Physics teachers, Thermodynamics, pedagogical content knowledge, alternative conceptions

Introduction

Inquiry into children's thinking about scientific concepts over the last few decades has led to increasing awareness about how children perceive and build internal representations of various phenomenological events (Duit and Treagust, 2012). Recognition of the process of learning as a perturbation in the existing equilibrium through constant interweaving of 'assimilation' and 'accommodation' (Piaget,1976) posit learners at the fulcrum of the teaching-learning process where-in knowledge of their existing ideas is a pre-requisite for teachers to design a pedagogical intervention for conceptual development (Vosniadou et al., 2001). From this constructivist standpoint, teachers are viewed as mediators in the process of child's personal construction of the world by creating creative classroom spaces that enable learners to find their voices (NCF, 2005). Facilitating learning in such a context requires teachers to familiarise themselves with knowledge of students' specific requirements for learning a particular concept, their alternative conceptions as well as learning difficulties. This knowledge of students is considered to be an essential domain of teacher's knowledge of teaching. It empowers teachers to pick a representation from their representational repertoire that creates dissatisfaction among learners with their existing conceptions, thus, creating conditions for conceptual change.

However, research on teacher knowledge has revealed that they lack a comprehensive understanding of students' reasoning and thinking about science concepts (Magnusson, Borko, & Krajcik, 1994). Considering science as an absolute, uncontested body of knowledge, science teachers often confine themselves to impersonal dissemination of 'fixed' textbook knowledge to learners who, according to them, do not seem to possess any relevant ideas (Scott, 1987).

* Assistant Professor (Science Education), Lady Shri Ram College for Women, University of Delhi Lajpat Nagar, New Delhi-110024, Email id: srhythm7@gmail.com

Although such concerns regarding teachers' traditional beliefs and knowledge about science teaching and learning have been articulated in literature (Fives, et al., 2015), no clear pathways have been formulated which promote topic-specific knowledge of learners' thinking among teachers through 'reflection-on-action'. Even in cases where teachers acknowledge the importance of probing students' intuitive ideas, they fail to understand its implications on organising classroom processes. Their own limitations in terms of a lack of comprehensive content knowledge prevent them from designing appropriate pedagogical tasks to address students' learning difficulties (Dawkins, et al., 2008). One of the reasons for such gaps is the failure of teacher education programmes to address content and pedagogy in an integrated manner and encourage teacher learning through inquiry into classroom processes (NCFTE, 2009/10).

In light of the arguments presented above, this study aimed at exploring and strengthening teachers' knowledge of students' conceptions about Laws of Thermodynamics and Kinetic Theory of Gases—a topic that is an integral part of both physics and chemistry curriculum. During my experience of teaching physics, I found learners and teachers struggling to understand the basic tenets of thermodynamics. The absence of hands-on activities in the school curriculum to support the understanding of the complex concepts made it tougher for pupils to comprehend the abstract ideas. Students' learning difficulties and alternative conceptions related to Thermodynamics have been identified in research (eg., Loverude et al., 2002) but little literature exists on teachers' understanding of the students' ideas about these topics. This study recognises the dearth of research in this field and therefore, attempts to contribute in this area by inviting teachers to participate in a research-based programme designed to strengthen teacher knowledge about students.

Theoretical Framework

Research into children's alternative conceptions in science has led to the emergence of perspectives on how children's conceptions interact with new incompatible ideas and result in a conceptual change. Despite disagreements on the process of knowledge construction in science, there has been a growing realisation among researchers and educationists that children's naïve conceptions are not 'wrong' and 'distorted' ideas to be ignored or discarded. Instead, these conceptions, constructed by children using their reasoning and logic, need to be identified and elicited as they serve as important 'raw materials' to introduce a conceptual change towards scientifically accepted explanations. These constructivist perspectives on conceptual change informed the design of the study.

One view on conceptual change, broadly termed as 'knowledge-as-theory' (eg. Posner et al., 1982; McCloskey, 1983; Vosnaidou, 1994; Chi et al., 1994) classifies children's personal constructions as coherent, systematic representations of the world. Drawing parallels between Kuhn's description of progress of science (Kuhn, 1962) and conceptual change, this view argues that a radical change in child's naïve views may happen if the child is dissatisfied with the existing conceptions and finds the new idea intelligible, plausible and fruitful (Posner et al., 1982). Arguing conceptual change to be a gradual process, Vosniadou (1994) proposed a 'framework theory' according to which, children's conceptions are constrained by their underlying suppositions within which they are embedded. When confronted with new information, they may attempt to fit it into the existing underlying suppositions resulting in misconceptions or synthetic models. For example, Vosniadou & Kempner (1993) found that children's presupposition that hotness and coldness is a characteristic of objects constrained the sense they made of their observations of thermal phenomena. The process of initiating a conceptual change, therefore, requires teachers to identify the existing suppositions underlying their naïve conceptions and design learning experiences that helps learners recognise the inadequacy of the existing frameworks in solving the problem at hand. The other view on conceptual change, termed as 'knowledge as pieces' assumes children's conceptions to be fragmented and discrete elements, organised in the form of cognitive structures called *p-prims* (DiSessa, 1993). It is due to the activation of an alternate p-prim by a child in response to a question that results in a wrong answer. The process of conceptual change, thus, requires the use of instructional strategies that aid in re-organization of the prior notions among children in order to develop a scientific understanding of the natural world (DiSessa, 1993).

It is worth noting that the perspectives explicated above argue against instructional practices aiming at straightforward exposition of scientific facts and emphasise the need for eliciting children's prior conceptions and underlying presuppositions to bring about a shift in their naïve conceptions. Recognising teachers as potential change agents, it emphasises the need to probe and identify pupils' prior notions and beliefs and learn to take their points of view into consideration while designing instructional strategies. By making students aware of their implicit representations, teachers could lead them towards understanding the limitations of their explanations and motivate to change them.

Outline of The Study

Any reform in science education cannot be actualised until it takes into account the perspectives of teachers and students. The study was carried out in multiple phases with 160 students and 30 physics teachers from 19 schools in Delhi as participants. Various methods of qualitative research including interviews, questionnaires, design experiment as well as classroom observations were used for data collection over a period of two years to develop an understanding of complexities of dynamic educational settings (Kelly & Lesh, 2000). Before probing teachers' understanding about students' ideas, it was important to gauge students' thinking about these topics and identify common conceptual difficulties and alternative conceptions. Therefore, in the first phase of the study, I set out to explore students' conceptions about thermodynamic phenomena from macroscopic as well as microscopic perspective through questionnaires comprising conceptual problems. The attempt was not to record the number of right or wrong answers but understand the reasoning employed by students to arrive at the answer. The responses from 160 students of government and private schools provided insights into their thinking about thermal phenomena and raised the following questions which guided the subsequent phases of the study: Do teachers possess knowledge of students' alternative conceptions? What are their beliefs regarding the role of learners' conceptions in instructional planning? How do these beliefs and knowledge about learners influence classroom processes? To understand how their beliefs and knowledge about students' conceptions shaped the discourse of classroom process, I interviewed the physics faculty teaching in those schools and observed the classroom interaction during teaching of thermodynamics. We engaged in discussion around several issues related to teaching-learning of these topics including core concepts of thermodynamics and kinetic theory of gases that the students were supposed to learn; how students think about the specific concept and different ways used by the teacher to unpack and represent the content to make it learnable. Discussion on topic-specific tasks provided an opportunity to teachers to reflect on classroom processes which helped me gain insights into their beliefs, pedagogical decisions and challenges faced in addressing students' alternative conceptions. It has been found that teachers' stated beliefs might differ from the enacted beliefs (Haney & McArthur, 2002) due to a variety of reasons including time constraints, paucity of resources, administrative responsibilities, etc. The classroom observations helped me in understanding and categorizing beliefs that teachers deemed central to their teaching-learning as well as the ones that were articulated in the interviews but could not be actualised in practice.

The insights gained from the conversations with teachers and observations of their classroom processes informed the design of the workshop which aimed to empower teachers to collectively build an understanding of students' thinking about thermodynamics through sharing of experiences, critically evaluating their practice, engaging in conversations around students' work and conceptions identified in the first phase of the study and exploring alternate methods to address the erroneous notions. During the course of the nine-day workshop, 30 teachers participated in various content-specific tasks, hands-on activities and inquiry-oriented problems to develop teaching practices that are more responsive to development of students' understanding. We explored the meaning and role of scientific modeling in physics through tasks that called for using models as tools for making predictions and providing explanations. These interactions enabled teachers to reflect on the role of representations in physics teaching-learning to embody objects, interactions and processes. Further, it provided an opportunity to teachers to understand the inherent assumptions in modeling, its possibilities and limitations, thus, helping them to look at textbook representations critically. Several representations given in the textbook were examined for the alternative conceptions they may promote among children if the assumptions are not made explicit. It was noticed during classroom observations that teachers' core belief of viewing Thermodynamics as an abstract, theoretical topic translated into teaching practices involving memorisation of definitions and practicing derivations. Such beliefs were debunked in the workshop through discussion on problems involving application of thermodynamics in daily life, demonstration of hands-on activities designed to address students' alternative conceptions as well as exploring the affordances of technological tools, such as, Geogebra and Netlogo in helping students model and visualise the behavior of gases and identifying the critical features of the 'object of learning' (Ling Lo, 2012). The teacher-researcher relation visualised in this study was that of scaffolding and conducting collective inquiry into students' responses and ways in which these ideas can be challenged and scaffolded. The goal of this design experiment (Cobb et al., 2003) was to evolve a research-based model from the richness of students' topic-specific ideas and teachers' practices that could serve as a potential exemplar of teacher learning and science teacher education.

Findings & Reflections

NCF (2005) advocates designing of learner-centred pedagogical approaches and relating school subjects to daily lives of the learners. However, changing instructional strategies without taking into consideration 'teacher thinking' would only result in teachers making superficial changes towards using learner-centred approaches in the classroom (Cohen, 1990). The purpose of the present study was to engage teachers in a collaborative inquiry towards reflecting on their beliefs and topic-specific knowledge about learners through a research-based programme. The analysis of students' responses to questionnaires revealed that they struggled to make sense of some fundamental concepts of thermodynamics, resulting in alternative conceptions. Irrespective of the school the students belonged to, they were found to be having difficulties comprehending the concept of thermal equilibrium, relationship between work and heat, multivariate relationships such as the ideal gas law, visualizing the the behaviour of gases under ideal conditions, etc. This indicated commonalities and overlaps in the nature of conceptual difficulties faced by students across contexts.

Many of these alternative conceptions arose due to erroneous underlying suppositions concerning the concepts of temperature, heat transfer, pressure and the relationship between them. For instance, it was found that students possess an inadequate understanding of the ideal gas law— a fundamental law in Thermodynamics. The ideal gas, $PV=nRT$ defines relationship between four thermodynamic variables, pressure, volume, temperature, number of moles that define thermodynamic state of a system. It was observed that students struggle with multivariable relationships such as the ideal gas law and often consider only two variables at a time. For example, when asked about the change in volume of the gas, one student wrote, "*Volume will decrease because pressure increases*". There was no mention of the variation in temperature during the process. They failed to take into cognizance that for the law to be applicable in this case, the remaining two thermodynamic variables (temperature and number of moles of the gas) must remain unchanged. Similarly, another student commented, "*Pressure will increase because temperature increases*". Here, the student seemed to believe that pressure is always proportional to temperature, irrespective of the variation in gas volume. It was seen that students made a preferential association between the variables depending upon convenience without recognizing the contradiction in their responses.

Moreover, it was seen that students often resorted to microscopic model while offering explanation for thermodynamic phenomena. However, many of these explanations reflected a faulty understanding of the microscopic model. For example, while predicting the reason for change in pressure, a student wrote, "*Pressure will not change as kinetic energy of the molecules is same*". Here, although the student was correct in saying that the pressure would not change, the reasoning offered pointed towards an incorrect understanding of the microscopic model of gas where it was assumed that any change in (average) kinetic energy of the molecules would always correspond to a change in pressure. This was a very common alternative conception found among students. They seemed to believe that for every thermodynamic process, increase in the number of molecular collisions would forbid free movement of molecules, thus, decreasing the average kinetic energy per molecule of gas. Students' alternative conceptions were identified for other thermodynamic processes as well including adiabatic process and isothermal process.

The insights into students' thinking guided the subsequent phase which involved investigation into teachers' knowledge about students. Teachers' interviews revealed that most of the students' conceptual difficulties were rooted in teachers' inability to comprehend and explain these concepts in the classroom. With regard to ideal gas law, it was found that teachers too, made a preferential relationship between any two gas variables and assumed that pressure being directly proportional to temperature (ignoring change in volume) would decrease. Likewise, students' tendency to think of an explanation in microscopic terms was found to be prevalent among teachers as well with many of them offering explanation of change in pressure in terms of collisions and average kinetic energy per molecule. It was suggested by students and teachers alike that a change in average kinetic energy will always lead to lesser number of molecules colliding with the walls of the container. A teacher claimed, "*Pressure will also decrease. When the temperature decreases, molecules will become less energetic, so they will transfer less momentum in the collisions. That is why pressure decreases.*"

Interaction with teachers during the interviews revealed their alignment with transmissionist view of teaching where the focus was on practicing numericals, learning definitions, memorising steps of derivations of formulae instead of emphasing the need of probing students' alternative ideas and underlying suppositions. Certain core practices were found to be used regularly by teachers. These included strictly following the textbook, avoiding students' mistakes by emphasizing correct answers, absence of critical voices, focus on expected answers and lack of experiential learning experiences. It was observed that despite several years of experience of teaching, teachers possessed an inadequate understanding of students' ideas about thermal phenomena and the ways in which appropriate learning environments could be designed to address them in the classroom. They struggled to provide justification for students' responses to the questionnaire and the underlying conceptual difficulties. I also found that teachers' identification of gaps in students' reasoning was constrained by their limited conceptual knowledge of the laws of thermodynamics and kinetic theory of gases.

With the aim of strengthening teachers' 'pedagogical content knowledge' (Shulman, 1986), the workshop helped in initiating a dialogue among teachers on pedagogical issues that arise in the context of teaching as well as examining their own content knowledge and beliefs through assertions, arguments and counter-arguments in response to the tasks and activities. For instance, an activity was designed by me to address students' and teachers' alternative conceptions about the relationship between gas pressure, volume and temperature (ideal gas law). As shown in Figure1 below, pressure and volume were varied using a pressure gauge and syringe and the readings were recorded on the laptop using an Arduino board.

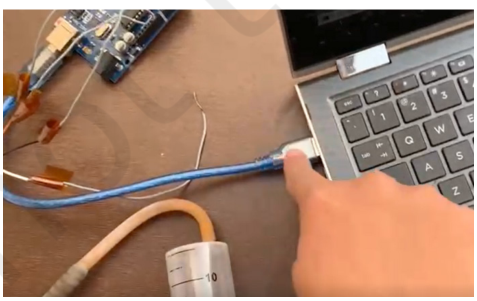

Figure: 1

The graph illustrated an inverse relationship between pressure and volume at constant temperature, thus, demonstrating the Gas law. Such activities helped in demonstrating ways in which knowledge about students' ideas could be used as the basis of designing pedagogical activities to address their alternative conceptions.

Similarly, visualization of microscopic behavior of gas to understand changes in gas variables was facilitated through an agent-based modeling environment (Netlogo). For instance, the following model (Figure 2) was constructed by me to help teachers in visualising the invariance in average kinetic energy of gas when the gas expands into empty space. This helped in addressing teachers' and students' conceptions related to factors affecting change in the average kinetic energy of gas per molecule. It showed that average kinetic energy per molecule of the gas would not change with the increase in gas volume due to free expansion.

During the sessions, teachers also engaged in critical examination of diagrams, definitions given in the textbooks and recognize how representations and their own teaching could be sources of misconceptions among students. Teachers' learning from the workshop was reflected in their feedback and responses to the questionnaire given to them at the end of the workshop. Sharing her experience of exploring these resources, a teacher said, *"I never thought adiabatic and isothermal processes could be explained in such an interesting manner"*. They appreciated the tasks and activities conducted during the sessions and requested for similar workshops for other physics topics as well. Teachers mentioned that the sessions made them reflect on their own understanding as well as students' thinking about thermodynamics and how important it is for lesson planning and addressing students' alternative conceptions. The sessions provided an opportunity to teachers to understand how learners' voices and conceptions could be the basis for decision-making and designing of pedagogical approaches for teaching-learning of thermodynamics.

Conclusion

The study attempted to understand and strengthen teachers' knowledge about learners' thinking regarding thermodynamics and kinetic theory of gases. Understanding students' constructs about scientific concepts constitutes an essential component of teachers' pedagogical content knowledge. It was found during the course of the study that teachers lacked a comprehensive knowledge about content and students' topic-specific ideas. The teacher engagement that happened during the workshop sessions illustrated how opportunities for teacher learning can be created through shared reflection on students' topic-specific responses, identifying the 'critical features' that need to be emphasized while teaching of a concept, encouraging them to articulate their beliefs and conceptions as well as laying down the criteria for designing and assessing teaching resources.

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