A Framework for Describing Some Aspects of PCK

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This paper describes a framework for investigating and analysing physics teachers' knowledge and beliefs about teaching and learning motion tasks. Problem solving is used as a theoretical lens of this framework. In order to assess teachers' self-reflection and awareness of problem-solving strategies, two problem based probes derived from a Problem Centred Questionnaire (PCQ); and a Problem Centred Interview (PCI) were used. Through problem solving, the teachers' pedagogical content knowledge (PCK) was evaluated and this led to exploration of the teachers' cognition. The analytical template developed in this study can be used as a guide for instructional intervention and curriculum development, or to interpret a teacher belief about the interpretation and feedback on student responses.

Introduction

Teachers' thinking about problem solving is important, because problem solving is an important component of learning in many disciplines in particular physics. Teacher thinking was defined by Kagan (1990, p. 421) as "beliefs and knowledge about teaching, students, and content; and/or awareness of problem-solving strategies endemic to classroom teaching". My investigation of teacher beliefs about effective teaching approaches for teaching problem solving in the physics topic of motion was part of the investigation of teacher intentions. The use of problem solving as a goal and a method was chosen so as to explore teachers' socially situated intentional or skilled thinking. This is consistent with social ontological approaches that Kagan (1990) suggested for exploring teachers' cognition including "multimethod evaluations of teachers' pedagogical content knowledge" and "taxonomies used to assess teachers' self- reflection and awareness of problem-solving strategies" (p. 422). Therefore, collecting and exploring teachers' cognition, beliefs and intention about solving problem and/or commenting on student written solution to the tasks is valuable for understanding some aspects of teacher pedagogical content knowledge.

A review of literature in this field reveals that, though there have been broad studies exploring teacher pedagogical content knowledge, the area of teacher thinking, intentions, and beliefs concerning problem solving and responding to student written solutions has received little attention. This empirical research project[1]

[1] Extracted from my PhD research at The University of Melbourne funded by Melbourne International Research Scholarships (MIRS)

aimed to investigate teachers' thinking and approaches through exploring different aspects of their pedagogical content knowledge. Teachers' thinking and approaches were explored in the context of solving linear motion tasks.

This paper discusses an effective method for gaining access to the physics teachers' thinking about problem solving, in which a qualitative research approach was considered the most appropriate. "Qualitative methods typically produce a wealth of detailed information about a much smaller number of people and cases. This increases the depth of understanding of the cases and situations studied" (Pattern, p.14). In the current study I analysed teacher role intentions in representing disciplinary content and in responding to student constructions as expressed in their accounts of their teaching in a number of conversations. These conversations concerned teacher interpretations of different student solutions to different linear motion tasks, their feedback to the student solutions, their ideal strategy for teaching motion problem solving tactics to students and their own solutions to a non-standard teaching task. The conversations with each physics teacher led to 11 case studies of physics teachers' skilled or intentional knowledge, and these differentiated teaching identities were then compared to creat various groupings of these individuals' levels of propositional knowledge and dispositional knowledge or beliefs as proposed by Magnusson, Krajcik and Borko (1999), in the context of providing meaningful feedback to students on their attempted solutions at problem solving.

This research seeks to describe teacher purposive thinking in their discursive practice (Harré, 1990) in teaching linear motion tasks. I used surrogate student solutions. A lack of resourcing limited opportunity for the researcher to use authentic teacher discussions with their students.

Literature Review

Since problem solving is central in this paper, it is important to review some literature on the definitions of problem solving. For instance, Resnick and Glaser (1976) have defined a problem as, "a situation in which an individual is called upon to perform a task not previously encountered and for which externally provided instructions does not specify completely the mode of solution" (p. 209). Lesh and Zawojewski (2007) proposed new definitions for a problem and for problem solving in which "a task, or goal-directed activity, becomes a problem (or problematic) when the problem solver (which may be a collaborating group of specialists) needs to develop a more productive way of thinking about the given situation" (2007, p. 782). In this regard, these authors stated that problem solving involves "the process of interpreting a situation,… involves several iterative cycles of expressing, testing and revising … and of sorting out, integrating, modifying, revising, or refining" various concepts involved in this process (2007, p. 782), and this range of meanings applies in this paper, unless otherwise indicated.

However, this kind of task is atypical in the teaching of both physics and mathematics, where students learn to solve standard tasks by working through worked examples (consisting of a problem statement and the appropriate steps to solutions) or conventional problems (appearing at the end of textbook chapters) that depend heavily on the level of learner's knowledge. The motion with constant acceleration problems that were used in this study are both standard and non-standard tasks. I will call them motion tasks throughout this manuscript.

Overview of study

Based on the aims of this study, it was decided to use a case study approach for the physics teachers incorporating a Problem Centred Questionnaire (PCQ) and a Problem Centred Interview (PCI) that included participants solving standard and non-standard motion tasks. Eleven physics teachers currently working at a number of different secondary schools in Melbourne agreed to participate in the study. To address the research questions, a PCQ and a qualitative PCI were used. These instruments (the PCQ and PCI) facilitated explorations of the interplay of teachers' inductive and deductive thinking, which contribute to increasing the researcher's knowledge of participants' problem solving approaches and content knowledge, participants' awareness of student difficulties, and their responses to these difficulties in motion tasks. Instead of the superficial analysis of a traditional content analysis (e.g., Wundt, 1928), a "qualitative content analysis" approach that represented an "empirical, methodological controlled analysis of texts within their context of communication", was employed to identify the "themes and main ideas of the text" (Mayring, 2000, p. 2). Thus, through qualitative content analysis of teachers' written responses to the hypothetical written student solutions, it might be possible to identify the main ideas and intentions of each teacher in the study. Following qualitative content analysis of the PCQ, physics teachers were interviewed through a PCI approach, through discussing and, and re-questioning, in a face-to-face flowing conversation, using a set of guiding questions. I developed an understanding of the interviewee's views, by using indirect questioning, discussions, and a gradual communication, to address the research questions (Witzel, 2000). The teachers' responses to the PCI questions were subjected to qualitative content analysis to analyse the teacher intentions regarding their interpretations of, and feedback on student solutions to the standard and non-standard motion tasks. Teachers' personal problem solving strategy and their beliefs about teaching and learning motion tasks/topics were also explored in order to triangulate the exploration of teacher intentions when teaching and responding to student difficulties.

Data Collection and Participants.

Adequate and rich data was derived from eleven teachers' comments and responses to the PCQ and PCI, in order to explore the research questions. This process took about 15 months. A purposeful sampling technique was used, that is, "a case is selected because it serves the real purpose and objectives of the researcher of discovering, gaining insight, and understanding into a particularly chosen phenomenon' (Burns, 2000, p. 465). In purposeful sampling, information-rich cases are studied to illuminate the research question (Patton, 2002). The teachers' responses to the PCQ and PCI were then subjected to "qualitative content analysis" (Flick, 2002, 2006; Mayring, 2000) to analyse the teachers' intentions regarding their interpretations of, and feedback on student written solutions to the standard and non-standard motion tasks, as well as their comments on their personal teaching strategies used to solve these tasks. In the second step all eleven participants were involved in the PCI process.

Instruments Design.

In order to explore teachers' intentions embedded in their written comments, hypothetical student written solutions to a specially developed set of appropriate tasks in the linear motion context were used that drew on the aforementioned pilot study of high school and university physics student solutions to those tasks. In addition, the dialogue of some hypothetical student responses included in the study design, also originated from the pilot study. The idea of designing the PCQ comes from the questionnaire about modelling and argumentation/proof in teaching mathematics in Year 8-10 across different countries (Schwarz, Leung, Buchholtz, Kaiser, Stillman, Brown, et al., 2008). The PCQ consisted of three sections: In the first section, the teacher was asked to solve a standard task (see Figure 1) from the 2007, Year 12 physics exam in Victoria.

Fred is riding his bike on a level road at a speed of 5.0 m s^{-1}. The tail-light break is off. It takes 0.45 seconds to reach the ground.

Mary was watching Fred and saw the tail-light fall. Her view of the events is shown in the Figure below.

How far above the ground was the tail-light when it was attached?

Fred was at position A when the tail-light broke off, and at position B when it hit the ground.

Figure 1: Bike task.

This task can be easily solved through the use of algorithms. The teacher was then asked to provide a written interpretation of, and feedback on, three hypothetical students' (Chris, Rob, and Sue) written solutions and explanations of their problem solving strategies to the Bike task. This was necessary in order to address the research questions. The discussion and strategies of the three hypothetical students while solving the Bike task are explained below:

Rob's strategy: Rob used rote manipulation and employed the "recursive plug and chug approach" (Tuminaro, 2004) to solve the Bike task. He also incorrectly considered the final velocity, $V_f = 0$.

Chris's strategy: Chris had a high/reasonable level of understanding of the formula and of solving the task in the context of physics.

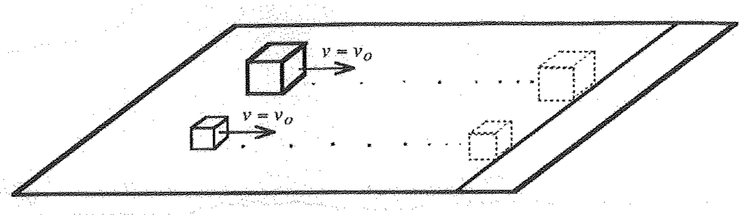
Sue's strategy: Sue solved this task mathematically. She had a poor understanding of the physics concepts used in the task, and consequently, she used speed instead of velocity. Sue tried to link the problem solving strategy and her real world, as she used her common sense to obtain the correct answer.

In the second section of the PCQ the teacher was asked to provide a written explanation of the way they usually introduce the formula $v = v_0 + at$ to students who have not previously seen it. In order to address the research questions three hypothetical students' explanations of their meaning for the equation $v = v_0 + at$ used in the PCQ. Each teacher was then asked to provide a written interpretation of, and feedback on, the three hypothetical student written explanations of the formula, which is not explained in this paper.

In the third section of the PCQ the teachers were asked to provide a written explanation of their background, including their qualifications, experience, and teaching areas. This information may have been needed to support understanding and interpreting the other data in relation to the research questions.

The PCI included a non-standard task (after Sherin, 2001) which was called the Shoved Block task (see Figure 2). All tasks were already modelled by a picture.

A block resting on a table is given a shove so that it slides across a table and eventually comes to rest because friction between the block and the table slows the block down. Now, suppose that the same experiment is done with a heavier block and a lighter block. Assuming that both blocks are started with the same initial velocity, which block travels farther?



A heavier and a lighter block slide to a halt on a table.
Reference, Sherin, 2001, p. 488.

Figure 2: Shoved Block task.

The Shoved Block task was considered as non-standard task. This task cannot be easily solved by applying an algorithm. The purpose of choosing the non-standard task was to explore the teachers' deep understanding and content knowledge of physics concepts relevant to the topic of motion. In addition, I aimed to compare teacher perspectives when they articulated their teaching strategies for the standard task and the non-standard task.

The questions in the PCI were organised into four sections:

General questions about their choice of their occupation, as well as general questions about the teacher's views of their teaching of the kinematics topic, problem solving, modelling, and use of formulae in the motion task.

Questions that were concerned with strategies for teaching the Bike task, and teacher awareness of their students' difficulties (if any) with the Bike task, as well as re-examining any teacher responses to PCQ items which were not initially clear.

Questions regarding another standard task which is not the focus of this paper.

Questions regarding the Shoved Block task outlined in Figure 2, which explored the teachers' purposes and strategies were introduced when they were presented with the challenge of teaching and using the formulae in solving the Shoved Block task. These questions were followed by the teachers' general feedback to, and their thinking about their students' difficulties in solving the Shoved Block Task. These were then followed by some questions concerned with the teacher interpretations and feedback on the written explanations about solving the Shoved Block task provided by the students Karl and Mike (Sherin, 2001, pp. 488-489). These are detailed in Figure 3.

Karl: Yeah, that's true. But I still say that the heavier object will take the longer distance to stop than a lighter object, just as a matter of common sense.

… I think that the only thing that it could be is that the coefficient
of friction is not constant. And the coefficient of friction actually varies
with the weight… I guess what we're saying is that the larger the weight,
the less the coefficient of friction would be.… Well yeah maybe you
could consider the frictional force as having two components.
One that goes to zero and the other one that's constant.
So that one component would be dependent on the weight. And the
other component would be independent of the weight.

Mike: So, do you mean the sliding friction would be dependent on the weight?

Karl: Well I'm talking about the sliding friction would have two components. One component would be fixed based on whatever it's made out of. The other component would be a function of the normal force. The larger the normal force, the smaller that component. So that it would approach a - it would approach a finite limit. It would approach a limit that would never be zero, but the heavier the object, the less the coefficient of friction at the same time.

Mike: I don't remember reading that at all. [laughs]

Karl: See, I'm just inventing my own brand of physics here. But, if I had to come up with a way - if I had to come up with a way that would get this equation to match with what I think is experience, then I would have to - that's what I would have to say that the…

Mike: Actually, it wouldn't be hard to …

Karl: the coefficient of friction has two components. One that's a constant

and one that varies inversely as the weight.

Figure 3: Mike and Karl's discussion about solving the non-standard task.

Analysis of the teacher written comments revealed how they interpreted and constructed feedback on the student written solutions. Subsequently, a follow-up interview with the teachers allowed further probing of their thoughts about their written interpretations and feedback on student solutions.

Implications

This study has developed a framework for exploring some aspects of physics teachers' knowledge in the motion topic. It appears from initial explorations that the PCQ and PCI have the capacity to reveal subtle differences between teachers' responses, and these might be attributable to differences in teachers' PCK. The PCI and PCQ, articulated a variety of the situations and tasks, can be used as a tool and guide to provide the multi-method evaluations of teachers' pedagogical content knowledge, in terms of their intentions and beliefs about interpreting and providing feedback to students' written responses. This allows the teachers to justify and release their beliefs about their teaching strategy and their awareness of students' difficulties.

This could form a background for a larger study, where PCK could be examined in the context of teaching physics in a secondary classroom. "From minds hidden in the heads of individuals, the study contributes to the use of mind talk" between teacher and students. This is, as Shotter (2006) suggests, a developmental investigation.

In addition, this methodology could be generalised and applied to other disciplines beyond physics as a guide for curriculum development, in order to examine teacher beliefs with respect to their interpretation and feedback on student responses in other discipline and topics.

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