Physics Teachers’ Responses on Student Solutions When Using Motion Tasks

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Melbourne Graduate School of Education
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This thesis is dedicated to

My mother, Simin who is always encouraging …
Abstract

This study was conducted with eleven upper secondary school physics teachers in the state of Victoria, Australia. The study involved investigating and describing teachers’ thinking, intentions or beliefs when they interpreted and provided feedback on hypothetical students written solutions to the linear motion tasks.

To obtain an in-depth understanding of teachers’ thinking and approach when responding to student written solutions, a qualitative approach incorporating a case study design was chosen. Two different data sources derived from a Problem Centred Questionnaire (PCQ); and a Problem Centred Interview (PCI) were used. Data processing was conducted in two main phases: the Initial and Comparative. With respect to teacher interpretations of, and feedback on student solutions, the comparative analysis explored patterns or relationships between teachers’ foci across aspects of the student solutions and motion tasks. A major finding of this study is that teachers’ interpretations and feedback on student solutions could be categorised in terms of the extent to which they attended to Student Thinking and Disciplinary Thinking. The analysis suggested that the initial assumption of this and most other studies which proposed that the provision of meaningful feedback on incorrect student solutions would require a high level of teacher content knowledge, and a concurrent attention to both ‘student thinking’ and ‘disciplinary thinking’, may be simplistic. There were found three patterns of relationships between teachers’ feedback to student difficulties, and two forms of teacher knowledge - that is propositional content knowledge forms, and dispositional knowledge or beliefs about teaching- learning motion. The discursive practice of the teachers indicated that the nature of their feedback to student difficulties were more strongly associated with the nature of teachers’ beliefs about teaching and learning motion, than with their level of propositional knowledge, or their teaching experience. The implications of this study are explored for teaching and researching meaningful problem solving and understanding particularly in the apodeictic use of kinematics formulae in linear motion, which students involved. It is revealed from this study that student difficulties in problem solving are not simply of the intellect with problems that can be solved by the application of reasoning, but also difficulties of the will, orientational or relational difficulties, difficulties of a very different kind.
DECLARATION

This is to certify that:

(i) the thesis comprises only my original work towards the PhD except where indicated in the Preface,
(ii) due acknowledgement has been made in the text to all other material used,
(iii) the thesis is fewer than 100,000 words in length, exclusive of tables, maps, bibliographies and appendices.

Zahra Parvanehnezhadshirazian
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GLOSSARY:

CONTENT KNOWLEDGE = CK
DISCIPLINARY THINKING = DT
MOTION TASK = SEE EXAMPLES IN APPENDICES A AND B
NON-STANDARD TASK = A TYPE OF TASK NOT USED/EXCLUDED IN VCE PHYSICS CURRICULUM
PEDAGOGICAL CONTENT KNOWLEDGE = PCK
PHYSICAL SCIENCE STUDIES COMMITTEE = P.S.S.C
PROBLEM CENTRED INTERVIEW = PCI
PROBLEM CENTRED QUESTIONNAIRE = PCQ
STANDARD TASK = A TYPE OF TASK USED/INCLUDED IN VCE PHYSICS CURRICULUM
STUDENT THINKING = ST
VICTORIAN CERTIFICATE OF EDUCATION = VCE
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Chapter 1 : Introduction

1.1 Background

During my studies at tertiary education level I felt that using mathematics was critical for learning and understanding physics concepts, and solving physics tasks. It was interesting that mathematics was used differently in the physics and mathematics classrooms. While in a mathematics context, I tried to find ways of solving an equation, in a physics context I tried to describe, learn and understand physical principles derived from equations. I started teaching eighteen years ago, in a secondary school in Iran as a physics and mathematics teacher. One of the main reasons I selected this career was my interest in teaching physics, as well as my success as a student of mathematics and physics at university. As a physics teacher, I found that my secondary students experienced serious difficulties in conceptual understanding, particularly in the mechanics topics in physics. In physics problem solving, students had difficulty linking the disciplinary discourse with the conversational reality of the phenomena in life contexts. This was particularly evident in their attempts to relate the use of the standard kinematic formulae to their real life experience. Coming to Australia and working with students in physics classrooms and science laboratories in Victorian state public high schools, I found the same student difficulties with teachers’ use of mathematics in teaching physics, particularly in problem solving motion tasks.

Physics students are introduced to kinematics equations early in their study of mechanics. Kinematics deals with the motion of objects and “researchers have recognised the importance of this topic [kinematics] as a building block upon which other concepts are based” (Beichner, 1994, p. 750). Typically, students are expected to show they have learnt the physics concepts in the curriculum, before being introduced to more complex situations, by using kinematics equations to successfully solve motion tasks involving objects moving in a straight line. When helping students to acquire a depth of understanding of and a fluency in the application of skills to solving motion tasks, there are philosophical questions as well as cognitive psychological issues about the nature of concepts in physics of which physics teachers should be aware in attending to student difficulties.
These observations led to the current study in which I have explored physics teachers’ interpretations of, and feedback on, student responses or learning difficulties in the context of solving linear motion problems at the upper secondary level.

1.2 Problem Statement

At tertiary level Sharma, Mills, Mendez, and Pollard (2005), have reported that amongst first year university physics students in Australia, students who are weak in mathematics and in physics have a poor understanding of physics concepts and how to apply them. Other researchers have observed that students at both tertiary level and in secondary school have difficulty in understanding different concepts in physics, particularly those commonly involved in the area of motion problem solving (e.g. velocity, acceleration, displacement) (diSessa, 1993; Driver, Squires, Rushworth & Wood-Robinson, 1994; McDermott, 1993; Redish & Steinberg, 1999; Shaffer & McDermott, 2005). These authors have reported on the reasons for the student difficulties in Physics, and suggested that physics teachers should be more knowledgeable about each type of difficulty. One type of difficulty relates to the nature of motion tasks as they involve real life experience and students attempts to apply common-sense understandings to the problem situation. The second difficulty involves the application of mathematics and formulae used in motion tasks, which leads students to attempt to solve the problem task using mathematical substitution, but without understanding the underlying physics ideas. Their arguments are detailed later.

The foregoing led me to investigate physics teachers’ thinking and intentions in relation to the use of mathematics (e.g. kinematics equations) and the solving of motion tasks in the context of teaching physics. My study also examined teacher responses to student attempted solutions of linear motion tasks. I explored components of teacher pedagogical content knowledge including their knowledge and beliefs about problem solving and their practices in responding to student solutions to linear motion tasks. These components include: (1) teacher knowledge and understanding of the content, or content knowledge (CK); (2) knowledge and beliefs about student understanding of specific science topics; and (3) knowledge and beliefs about teaching and learning science, particularly in linear motion tasks (Magnusson, Krajcik, & Borko, 1999). Consistent with Kagan (1990) and Mason (2004) in their reviews of research into teachers’ beliefs, I found the terms knowledge, belief, perspective, and view, were often given similar meanings and used interchangeably. In this research, I employ a classical
distinction between two types of teacher knowledge, the ‘what’ of content knowledge as propositional knowledge and after Ryle (1949), dispositional knowledge which encompasses both aspects of skilled knowledge (2 above) of ‘persons and their intent’ and (3 above) the ‘how’ to refer to different aspects of their thinking and intent.

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 teaching and responding to student answers to motion tasks has received little attention. This research focused on investigating 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. Kagan (1990) has noted the prominent position of problem solving as a teaching approach in physics teaching and learning.

The researcher’s perspective of teaching and learning science in the current study draws on a constructivist view of conceptual change which “places emphasis on developing new teaching and learning approaches that deliberately take students’ pre-instructional views, beliefs, and conceptions into account” (Duit, Niedderer & Schecker, 2007, p. 606). Constructivist views of conceptual change applied to this study suggest that to promote students’ conceptual understanding in linear motion, physics teachers should focus on the students’ views and thoughts as well as on the formal grammar of physics in the linear motion domain. Some studies of science teachers (e.g. Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001; Sanders, Borko, & Lockard, 1993) have suggested that teacher content knowledge generally underpins their feedback on student difficulties in the science area. Others, for example Magnusson et al. (1999) suggest that teacher dispositions or beliefs about how students learn and about effective teaching approaches in a specific topic influence teachers’ feedback in a particular context.

According to Magnusson et al. (1999), teachers who are aware of students’ difficulties have appropriate skills to provide specific responses to improve student learning difficulties about the topic. Appropriate teacher feedback on a student’s attempted solution is taken to include a well developed sequence of ideas addressing the individual student’s learning need, rather than a general response about student learning and/or the formal physics concepts of linear motion, or detailed information about the physics concepts. This assumes dual attention being given to disciplinary thinking and student thinking.
1.3 Research Aims

Teachers’ approaches to problem solving and their feedback to students were analyzed to explore teachers’ thinking (Kagan, 1990). Some literature (Clement, 1994; Sherin, 1996, 2001; Tuminaro, 2004) has suggested student understanding of the formulae used in physics is needed to solve problems with understanding, and I call this a meaningful problem solving strategy. Sherin (2001) developed a list of student schema in relation to the formulae used in physics contexts such as linear motion, and suggested using them to construct a teaching approach for solving problems. Since some literature (Driver et al., 1994; Redish & Steinberg, 1999; Shaffer & McDermott, 2005) has shown that students have considerable challenges in both understanding and solving linear motion tasks, I was interested in exploring teachers’ feedback, which is a main focus of this study. As noted earlier, there has been little attempt made to explore teachers’ skilled knowledge concerning their feedback on student difficulties arising during the process of problem solving in linear motion tasks. Therefore, I considered it important to address the following research questions:

1- How do high school physics teachers interpret correct and incorrect student solutions to standard textbook and incorrect student solutions to non-standard motion tasks in physics, and on student explanations of the physics formulae?

2- How do high school physics teachers provide feedback on correct and incorrect student solutions to standard textbook and incorrect student solutions to non-standard motion tasks in physics, and on student explanations of the physics formulae?

The necessary first step to investigating teachers’ feedback on the students’ responses was to determine how teachers interpret student thinking and responses. For both teacher interpretations of and feedback on student solutions, it was also important to examine how teachers themselves understand physics concepts when solving motion tasks, and to explore teacher beliefs about learning and teaching the linear motion topic, particularly in the area of problem solving and the use of formulae.

Based on the literature (Chapters 2 and 3), I made a number of assumptions concerning teachers’ thinking, intentions and approaches to providing feedback on different students’ responses for different types of linear motion tasks. For example, I assumed that teachers have a choice between focussing on the manipulation of the formulae and the process of problem solving, or giving meaning to the mathematics
(Tuminaro, 2004; Tuminaro & Redish, 2007), when providing feedback on a standard task. I also assumed that the teachers who had a rich content knowledge in the topic of linear motion were likely to be able to provide meaningful specific feedback on student solutions.

Therefore I chose a qualitative approach (Chapter 4) to produce detailed information about the thinking and intentions of a smaller number of teachers about their teaching and the learning of linear motion tasks. In order to develop and enhance Science educational research and to understand the reality of physics teaching it was important to increase the depth of my understanding of the cases and situations studied. The approach adopted enabled the investigator to design appropriate instruments to address the particular research questions to do with teachers’ dispositional and strategic as well as content knowledge in different contexts defined by the nature of the specific task and the nature of the particular student solution to the task.

1.4 Structure of the thesis

Chapter 2 offers a review of previous research on learning and teaching physics, particularly on the topic of motion, and a discussion of teachers’ PCK relevant to this study. I review the literature related to issues in learning the motion topic, including student ‘misconceptions’ and the use of the kinematics formulae. I also consider the literature related to the influences affecting successful physics problem solving. Finally components of teacher pedagogical content knowledge with regards to teaching and learning perspectives are explained.

In Chapter 3, a theoretical framework is developed, based on synthesising and linking the literature of conceptual change and problem solving, teacher content knowledge and pedagogical content knowledge. The literature on conceptual change and problem solving suggests that ‘good’ physics teachers: (a) pay attention to both student views and formal physics concepts in their teaching practice, and (b) develop meaningful problem solving approaches and have a rich content knowledge in the area of motion.

In Chapter 4, the research methodology is explained. I first describe the research approach used in this study. A number of problem tasks, both standard and non-standard, were used as settings for discussions with the teachers. Data collection including arrangements with the participants, and two instruments used, that is, a
problem-centred questionnaire (PCQ), and problem-centred interview (PCI), are detailed. The data derived both from individuals and in comparison among them, from these two instruments were studied in order to address the research questions. I next discuss the methodologies employed to analyse the data to address the two research questions. Finally, I present an example of an analysis of a teacher’s written responses to the questionnaire items, and to relevant excerpts from his interview.

In Chapter 5, the results and data analysis of teachers’ responses are presented. I first summarize the teachers’ backgrounds. Second, I analyse teacher beliefs about the teaching and learning of general and specific aspects of motion. I then categorise and explain the teacher interpretations and feedback, with respect to hypothetical students’ correct/incorrect responses, and the type of linear motion tasks.

In Chapter 6, discussion of teachers responses on student solutions are provided. Variations among the eleven teachers are first discussed. The relationships between teachers’ content knowledge in the area of motion and teachers’ dispositional knowledge or belief about teaching and learning motion, teachers’ interpretation of student solutions, and teachers’ feedback on such solutions are then explained. Teaching of motion tasks is finally discussed.

In Chapter 7, major findings including an examination and categorization of teachers’ feedback on student solutions, and relationships between teacher feedback and two forms of teachers’ knowledges that is dispositional knowledge and propositional knowledge are explained. Personal reflection on the nature of learning and teaching physics, limitations, and implications of this study are then explained and reflected upon.
Chapter 2: Literature Review

The current study involves a detailed examination of eleven physics teachers’ interpretations of, and feedback on, students’ solutions when solving linear motion tasks. This study is also an exploration of these teachers’ dispositional knowledge or beliefs about learning and teaching the linear motion topic. The literature relating to these aspects is examined and summarised in this chapter under four subheadings: Background (section 2.1), Learning the topic of motion (section 2.2), Factors affecting problem solving (section 2.3), and Relationship between key components of teacher knowledge and teaching approach (section 2.4).

2.1 Background

In many western countries including Australia, there is ongoing social concern about the declining number of physics students in schools and the limited numbers of physics graduates from university. The total enrolments in universities have significantly increased during the last two decades, but physics has not experienced a proportionate increase in student numbers. As Sharma, Mills, Mendez, and Pollard (2005) report, this is due to several factors, including the following:

... as physics is traditionally seen as being both difficult and mathematically based, it continues to be taken by the same sort of students who did it in the past, but has not benefited from the broader spread of student interests and academic offering in tertiary education. (p. 8)

University physics departments are now concerned that the new generation of students will not be as well prepared in physics as the previous generation. “As instructors, we are often surprised by how little math our students seem to know [in the context of physics], despite successful performances in their math classes” (Redish, 2005, p. 1). This is assumed to most obviously affect their facility with mathematical and physical equations and problem solving. In the Australian context, these poor skills may be due to the fact that students today have a “substantially poorer mathematical background than those of previous generations… and had less of the traditional physics preparation which includes a highly mathematical approach to physics” (Sharma et al., 2005, p. 16).

The foregoing implies that the development of student learning in physics requires a careful review of physics instruction, particularly in terms of the discursive practices of
physics teachers in classrooms in schools and universities, and particularly in the context of physics problem solving.

Dimensions of Physics teaching:

The argument explored in this research is that teaching physics through problem solving can be seen as a commitment to wedding disciplinary discourses and conversational realities. Teachers explain the forming and sustaining of disciplinary discourses of the type studied in this thesis in terms of systems of rules and conventions that students can “picture”. In a monological classical paradigm of explanatory science teaching, students get to know about objects at a distance. In contrast to this paradigm, in a dialogical paradigm of conversational teaching, teacher and students first get to know something, and then, from whatever relationship that might have formed between them, they jointly transact with their surroundings and negotiate between them how those conversational realities might best be communicated. A main source of failure to understand the concepts involved in physics teaching is lack of a clear view of the use of words and logic or grammar in a particular conversation between teacher and student. This in the problem solving format has the form: “do I (teacher) or you (student) know my/your way about” in the disciplinary discourse. The problem task functions as a perspicuous representation, of fundamental sensory and embodied common sense. It is an intermediate case that earmarks the way the teacher and students can in the joint-action of problem solving, open up a ‘space’ in which teacher and student can ‘see’ as others see, that is make sense, not only of words but give some kind of form to the shared judgment of their use. In the full conversational reality of physics teaching, teachers communicate not only what they know, but how they know it and how they value it.

Three types of knowledge (Shotter, 1990) are involved in this conversational reality:

1. Knowing that which can be stated in propositions or representations.
2. Knowing how – knowledge of craft or skill.
3. Knowing from within – common-sense knowledge, non-representational, embodied or moral knowledge. It is linked to people’s personal and social identities and determines the availability of the other two kinds of knowledge. It is a responsive form of knowledge whereby people can influence each other in their being rather than just in their intellects. It cannot be represented as an object of knowledge within a discourse as its nature is extraordinary.
Chapter 2 : Literature Review

The first type of knowledge is referred to in this thesis as disciplinary knowing and in much of the research literature as teacher’s content knowledge. The other two types of knowledge are referred to in some of the research reviewed as dispositional knowledge or teacher beliefs.

Science education research in several areas most pertinent to this study is briefly reviewed below. The first section looks at some research related to learning physics in the motion context (see 2.1.1). This is followed by a review of the literature related to general issues of problem solving in mathematics and in physics including the difficulty of defining the concept of ‘problem’ (see 2.1.2). Research that explores the characteristics of teachers’ knowledges is then reviewed (see 2.1.3). The research on teachers’ pedagogical content knowledge (PCK) and practice is examined (see 2.1.4).

2.1.1 Learning physics in the motion context

A number of learning theories have been applied to the domain of science teaching. These are based on the major theories of learning which underlie curriculum planning in schools and are generally classified into two groups: the “directed method and the constructivist method” (Roblyer & Edwards, 2000, p. 3). While the constructivist method has its basis in cognitive development (Piaget, 1970, 1983) and social constructivism (Vygotsky, 1978), the directed method is derived from behaviourism (Skinner, 1953) and instructional design (Gagne, 1985). In constructivist learning the teacher is seen to be a facilitator who stimulates the students’ critical thinking (Roblyer & Edwards, 2000). However, according to behaviourism, the teacher provides directed experiences for students. The fundamental elements of each lesson are taught sequentially, and then a response is expected from the student. Constructivism in its various forms is currently viewed as the dominant theoretical perspective in this field. Constructivists believe that students construct their new knowledge through an active participation in the learning process. Therefore, students should be provided with opportunities to construct knowledge internally, and to meaningfully apply knowledge in different contexts to develop the needed skills. This view has relatively recently been expanded to include social, particularly discursive, interaction as a key component. The social constructivist theory of learning has offered a new perspective suggesting that students should receive opportunities to interact with their peers and teachers to develop their knowledge (Boaler, 2001).
Chapter 2: Literature Review

The social constructive platform has redirected attention to teaching and learning. In this domain Marsh (2009) reviewed eighteen alternative teaching and learning modes available for teachers to use, ranging from “computer-based simulators and on-line learning, through problem-based learning and inquiry to cooperative learning” (pp. 56-57). Marsh argued that any mode of teaching and learning needs to be geared towards the topic to be taught as well as to a student’s individual needs. In the context of the current study, and in line with science instruction, it is broadly argued that students have struggled to understand physics concepts which are modeled purely mathematically (Nashon, 2005, 2006; Nashon, Anderson, & Nielsen, 2009; Sherin, 1996, 2001). With respect to understanding physics concepts, there are research studies which claim that most students who perform well in both mathematics and physics, separately, still cannot make substantial links between these two in order to understand the underlying scientific concepts (Carrejo, 2004; Carrejo & Marshall, 2007; Marshal & Carrejo, 2008; Redish, 2003, 2005; Redish & Steinberg, 1999; Sherin, 1996, 2001; Tuminaro, 2004; Tuminaro & Redish, 2007; Woolnough, 2000).

Redish (2005) argued that using mathematics in physics “has a different purpose — representing meaning about physical systems rather than expressing abstract relationships — and it even has a distinct semiotics — the way meaning is put into symbols — from pure mathematics” (p. 1). Mathematics education and mathematical psychology research communities have made progress in understanding students’ uses of mathematics in the context of mathematics courses (see for example, Lesh & Zawojewski, 2007; Lester, 2007; Reed, 1998; Schoenfeld, 1992; Törner, Schoenfeld & Reiss, 2007). These achievements in the mathematics education community are very relevant. However a coherent and meaningful description of a highly context dependent phenomenon — like using mathematics achievement in the context of physics — can only be achieved if the phenomenon is studied in its original setting. Although the results from the mathematics education community have implications for mathematics instruction, this study is concerned with teaching issues related to student use or understanding of the kinematics formulae in the context of solving physics motion tasks, particularly in relation to students’ difficulties.

Kinematics is a natural context involved in everyday life that is a “fundamental area of study that links the mathematics and physics … [for instance] the development of mathematical concepts such as function … [with an] understanding of critical [physical] ideas such as velocity and acceleration” (Carrejo & Marshall, 2007, p. 53). These
authors concluded that the aforementioned purpose (to combine the abstract and real-world aspects) is necessary to develop the understanding of physical concepts of the kinematics tasks.

A sound interpretation of the problem and construction of an appropriate strategy to solve a physics motion task requires an understanding of the underlying concepts of the kinematics variables involved. Difficulties that arise may be due to a lack of familiarity with conventions and/or the contexts to which the problem relate, as well as a disjunction between practices in mathematics and physics subjects (Forster, 2004; Roth, Woszczyna, & Smith, 1996; Woolnough, 2000). Forster (2004) also noted a particular misconception that occurred during physics problem solving involving movement, and thus, kinematic variables. For instance, an incorrect interpretation of zero velocity as zero acceleration existed in her study subjects. As Forster has stated, an “erroneous interpretation of velocity-time graphs is widely documented in the literature and is attributable to velocity being a derived quantity. Acceleration involves another derivation” (p. 251).

Redish (2005) also stated that in physics many different symbols are used, while in mathematics, “The choice of symbols tends to be narrowly restricted by category, [for example] in a one-variable-calculus class, the variable will almost always be an x, y, z, or t. Constants will typically represented as specific numbers” (p.1). In physics equations, between three to six symbols are commonly used, and equations with a single symbol are rare. Moreover, in physics different kinds of constants (e, h, …), problem parameters (m, R, …) and initial conditions (v₀, t₀, …) are used. But the most significant difference between mathematics and physics symbols is about the loading of meaning onto these symbols. Symbols in physics are used to activate a particular mental association with some physical quantities or measurements. Loading meanings onto symbols leads to differences in interpretation as well as the viewing of equations by mathematicians: firstly by representing the relationships, and secondly by “filtering the equations through the physics” (Redish, 2005, p. 4). A detailed review of the literature on student difficulties with using or understanding the mathematics in the motion tasks is discussed in section 2.2.

Because in the current study a central focus is student-teacher interaction concerning a problem solving strategy in linear motion tasks, it is important to consider the general research related to problem solving in the mathematics and physics contexts.
2.1.2 Problem solving in the mathematics and physics contexts

Prior to reviewing the literature on problem solving in mathematics and physics, it is important to define a ‘problem’ in the context of physics or mathematics. 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). However, Schoenfeld (1992) claimed that in mathematics the expression “problem solving” has been used with various meanings, ranging from “working rote exercises” to “doing mathematics as a professional” (p. 334), and this range of meanings applies in this thesis, unless otherwise indicated. Some authors have restricted the definition of mathematical problem solving to the process of “working on unfamiliar problems” (Schoenfeld, 1992, p. 356), “applying previously acquired knowledge in new and unfamiliar situations” (CDC: Curriculum Development Centre, Australia, 1982, p. 3), or to the struggle with new and unfamiliar tasks when the relevant solution is not known (Polya, 1957). Lesh and Zawojewski (2007) proposed new definitions for a problem and for problem solving. They stated that, “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).

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 are used in this study are both standard and non-standard tasks. I will call them motion tasks throughout this manuscript.

Manogue, Browne, Dray, and Edwards (2006), Redish (2005), Tuminaro (2004), and Tuminaro and Redish (2007) have argued that physicists and mathematicians view and use mathematics differently. While in a mathematics context we try to find ways of solving an equation, in a physics context we try to describe, learn and understand
physical principles derived from an equation. For example, Manogue et al. (2006) conducted a study on middle division physics students at Oregon State University. They tried to establish a better understanding of what makes the transition difficult from the lower division mathematics and physics to a high division, even for students with an A mark in their introductory courses. The middle division, the transition phase, consists of courses taken immediately after introductory calculus, introductory physics and modern physics and include electrostatics and magnetostatics. Manogue et al. (2006) reported that due to the nature of Ampere’s law problems, which involve both mathematics and physics concepts, students experienced considerable challenges in solving them. Manogue et al. (2006) also argued that, in physics, fundamental relationships between the physical quantities are described, while in mathematics a set of basic assumptions is pursued. For physics majors to be successful in their understanding of physics content, they needed a number of capabilities that might not be addressed by any traditional teaching approach. The result is that “the total cognitive load is too high for many students at the transition from the calculus and introductory physics sequences to upper division courses for physics majors” (Manogue et al., 2006, p. 344).

It has been widely believed that in physics teaching problem solving as a practice affords and enhances student performance and understanding of physics (Maloney, 1994; Scanlon, 1993). However, as Hobden (1998) noted, routine problem solving has frequently been found to be ineffective in promoting student understanding of physics concepts. diSessa (1993), Redish (1994), Sherin (1996, 2001), Tuminaro (2004), and Tumniaro and Redish (2007) and others have observed that a student problem solver is typically involved in a process comprising the following stages: (a) reading the problem, (b) taking note of the quantities given in the problem and the quantities that are needed, (c) writing the relevant equation(s) from memory (or from the board, in a classroom setting), (d) manipulating the numbers and expressions through a route from the given quantities to what is needed, and (e) obtaining the answer. Disciplinary thinking involves more than having skill in writing the quantities and recruiting the equations (from memory) and performing rote manipulations.

It has been argued by Conn (1995), McDermott (1993), and Redish and Steinberg (1999) that a good problem solver has a high level understanding of physics concepts (what the physics is about), and a well-developed knowledge structure (how the physics fits together). More recently, Gaigher, Rogan and Braun (2006, 2007) conducted a study
on 189 year 12 science students from sixteen schools in South Africa, divided into an experimental and a control group, to explore the development of conceptual understanding through structured problem solving in physics. They used a quasi experimental design with a pre-test and various post-tests. They found that structured problem solving involving qualitative analysis enabled high school students to demonstrate better conceptual understandings of physics, as these students tended to adopt a conceptual approach to problem solving. Gaigher et al. (2007) concluded that, “although the effect of problem-solving strategy on teacher development was not investigated in this study, it is possible that poorly trained science teachers could benefit in much the same way as their students” (p. 1108). The current study is concerned to provide finer grained descriptions of the discursive behavior of physics teachers using standard and non-standard linear motion tasks to teach problem-solving strategies as a necessary foundation to any attempt to transform such behavior.

The current research is not concerned with student problem solving per se, but rather, with physics teachers’ knowledge and beliefs about the use of the formulae in linear motion tasks, and relevant problem solving strategies. This study explores teachers’ knowledges as revealed in their interpretation and feedback on student solutions to the linear motion tasks. The foregoing suggests that for the purpose of this study, it is important to review general research related to teacher knowledges.

2.1.3 Characteristics of teachers’ knowledges

In the domain of science education, Shulman’s (1986, 1987) work has been very influential. He claimed effective teachers developed specialised disciplinary knowledge in framing and staging their instruction to help a diverse group of learners develop their scientific knowledge and understanding of the concept(s) involved. He developed the construct of PCK to distinguish the knowledge of an effective science teacher from a subject matter specialist, for example a physicist (Shulman, 1987).

Shulman (1986) stated that the idea of testing teachers’ skilled knowledge in subject matter and pedagogical skill(s) is not new, but has deep roots in American education. Initially the major concern in such testing was on the assessment of subject matter knowledge of teachers, rather than their pedagogical practice. He found that a century later the emphasis had changed, and more importance – in teacher appraisal – was put on teaching methods and teachers’ management and classroom activities. Shulman
(1999) observed that the missing paradigm in research studies on teaching is the study of teachers’ content knowledge (CK) and its interaction with pedagogy. Shulman (1986) described CK as, “the amount and organisation of knowledge per se in the mind of the teacher”, and stated that PCK, “goes beyond knowledge of subject matter knowledge for teaching” and refers to “the most useful forms of representation of ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations - in a word, the ways of representing and formulating the subject that make it comprehensible to others” (p. 9). PCK was defined by Shulman (1987), as the amalgamation of content knowledge and pedagogical knowledge, which identify the unique bodies of knowledge for teaching.

Grossman (1990), in a comprehensive description of teacher knowledge and teacher education identified four general areas of teacher knowledge as being, “general pedagogical knowledge, subject matter knowledge, pedagogical content knowledge, and knowledge of context” (p. 5). More recently, Loughran, Milroy, Berry, Gunstone, and Mulhall (2001) reported on a detailed study of experienced science teachers in which, through individual interviews, they attempted to capture the teachers’ pedagogical content knowledge. They have defined pedagogical content knowledge as, “the knowledge that a teacher uses to provide teaching situations that help learners make sense of particular science content” (p. 289). They argue along with others that pedagogical content knowledge is a highly complex entity which cannot easily be investigated because different domains cannot be viewed separately, as PCK is the amalgam of different aspects of teachers’ knowledge and beliefs, teachers’ classroom practice, and teachers’ decision making or assessment (Baxter & Lederman, 1999; Gess-Newsome & Lederman, 1999; Loughran et al., 2001; Magnusson, Krajcik & Borko, 1999; Shulman, 1987).

Magnusson et al. (1999), for instance, described pedagogical content knowledge as consisting of five components, including: “(a) orientations toward science teaching, (b) knowledge and beliefs about science curriculum, (c) knowledge and beliefs about students’ understanding of specific science topics, (d) knowledge and beliefs about assessment in science, and (e) knowledge and beliefs about instructional strategies for teaching science” (p. 97).

In an attempt to characterize the knowledge and skills for an ideal twenty-first century physics teacher, Etkina (2005) proposed the structure and course content of a
physics teacher preparation program. She described the pedagogical content knowledge of physics teachers as a unique blend of physics and pedagogy, and consisting of the knowledge of physics curriculum, knowledge of student difficulties, knowledge of effective instructional strategies for a particular concept, and knowledge of assessment methods. In a recent study on physics teachers describing the pedagogical practices of the Rutgers Physics (Physical Science Teacher Preparation Program), Etkina (2010) added ‘orientation toward teaching’ as another feature of PCK.

For physics teacher education majors at Illinois State University (ISU), a detailed outline of a required knowledge base has been established, since 1994. The required knowledge base was developed on, “the basis of many years experience with what high school physics teachers need to know, be able to do, and what dispositions they should possess in order to be effective” (ISU, 2009, p. 3). The physics teachers’ candidate knowledge base at ISU (2009) was comprised of the following characteristics: knowledge of physics, allied sciences, curriculum, students’ difficulties, teaching-learning relationship, authentic best practices and generic best practices, understanding of students and what the term ‘scientifically literate’ means, classroom management, communication skills, scientific and philosophical dispositions, social and technological context, learning environment, active and engaged learning, student assessment, self-assessment and reflective practice, technology of teaching, professional responsibilities, nature of science, and responsive teaching.

The major focus of this study, as already indicated is to describe physics teachers’ pedagogical content knowledge in terms of their level of propositional knowledge and dispositional knowledge as revealed in the feedback they felt they ought to provide to hypothetical student responses to linear motion tasks. There is a normative or moral aspect to this sense of oughtness or intent that is often neglected in the research on the practical epistemology of teachers (Sockett, 1987). The design of the study drew on Kagan’s (1990) review of research into teacher cognition, which she defined as, “pre- or in-service teachers’ self-reflections; beliefs and knowledge about teaching, students, and content; and awareness of problem-solving strategies endemic to classroom teaching” (p. 421). Kagan (1990) described five alternative approaches to investigating teachers’ cognition:

(a) Direct and non-inferential ways of assessing teacher belief, (b) methods that rely on contextual analyses of teachers' descriptive
language, (c) taxonomies used to assess teachers’ self-reflection and awareness of problem-solving strategies, (d) multi-method evaluations of teachers’ pedagogical content knowledge, and (e) concept mapping technique designed to reflect the structure of pedagogical knowledge as it resides in a teacher's long-term memory. (p. 422)

The approaches (c) and (d) were used in this study to examine eleven upper secondary school physics teachers’ cognition levels. I examined and used teacher beliefs about teaching and their content knowledge in solving motion tasks, as well as the teacher interpretations of, and feedback on student difficulties. Consistent with the Kagan (1990) review of research into teachers’ beliefs, I found the terms knowledge, belief, perspective, and view, were often given similar meanings and used interchangeably. As indicated above I employ the minimal common language distinction between propositional knowledge of “that”, and dispositional knowledge that combines knowledge “of how” and knowledge “held within”. This allows a distinction between that knowledge which is held as intransigent or external and knowledge held as transigent or internal to indicate two different aspects of teachers’ attention and intent in their transactions with students.

In the domain of science education various models for PCK have been introduced. To clarify their relevance to this study, some of them are explained below.

2.1.4 Teachers’ PCK and practice

As previously mentioned (see section 2.1.3), pedagogical content knowledge is the general term used to describe the essential knowledge of exemplary teachers (Shulman, 1986, 1987), and comprises several domains of knowledge such as subject matter knowledge, pedagogical knowledge and knowledge of context (Magnusson et al., 1999). In the literature, a number of models have been applied to science teachers. For instance, Magnusson et al. (1999) used a PCK model to illustrate the interaction of these domains of knowledge in the development of the PCK of different individual teachers (Figure 2.1).
The development of personal PCK may be influenced unequally by the development of each of these domains. To illustrate these different influences, Magnusson et al. (1999) in their model, introduced two hypothetical science teachers (Figure 2.1). As shown in this figure, teacher A has acquired more subject matter knowledge than the two other important forms of knowledge (pedagogical knowledge and knowledge of context), which is likely to influence the development of their personal PCK (shaded box). However, teacher B has acquired more pedagogical knowledge compared to the two other types of knowledge (subject matter knowledge, and knowledge of context), indicating their personal PCK development is likely to be more strongly influenced by pedagogical knowledge. In teaching a similar topic in a similar educational context, this difference may mean that these two teachers exhibit different PCKs. However, we would expect a significant overlap in the PCK developed by each of these teachers (Magnusson et al., 1999), because both teachers have common purposes that involve improving student understanding of a particular topic, for example motion.

Duit, Niedderer, and Schecker (2007) also took the cognitive subject matter issue seriously into account for physics instructional planning. They argued that “the Didaktik tradition allows an improvement of instruction by developing a content structure for instruction that addresses students’ learning needs and capabilities as well as the aims for instruction” (p. 601). This structuring of the teacher’s mind is elaborated in Figure 2.2, which points to the importance of the transformation of physics content into a structure for instruction. In brief, in the first phase, the ideas of content (e.g. force) have to be simplified (elementarization) and then to be elaborated by being put
into contexts thought to be familiar, which help improve student understanding. These processes clearly draw on the authority of experience to justify their use. These two basic phases in the development of a content structure for instruction are “intimately interrelated to decisions on the aims of teaching the content and the students’ affective and cognitive perspectives” (p. 602).

Reference: Duit et al., 2007, p. 602.

**Figure 2.2:** Educational reconstruction of physics content structure.

Shulman’s broader interest in research into practical epistemologies of teaching in different school subject traditions, shares with Duit’s European Didaktik tradition, a concern for disciplinary content to be taken seriously in accounts of instructional planning. Both Shulman and Duit et al. express a concern for teachers’ understanding of students’ understandings, dispositions and needs.

Since the 1980s, research in teaching and learning science, previously influenced by behaviorist psychology, has been influenced by cognitive science constructivist views of conceptual change. This research perspective “places emphasis on developing new teaching and learning approaches that deliberately take students pre-instructional views, beliefs, and conceptions into account” (Duit, et al., 2007, p. 606). In science education, constructivist models of learning suggest that the students’ existing knowledge or
misconception or lay conception (Magnusson et al., 1999) is basic in the construction of students’ learning and understanding in formal school instructions.

As a physics professor who teaches undergraduate students, Redish (1994) has argued:

If we are to make serious progress in reaching a larger fraction of our students, we will have to shift our emphasis from the physics content we enjoy and love so well to the students themselves and their learning. We must ask not only what do we want them to learn, but what do they know when they come in and how do they interact with and respond to the learning environment and content we provide. (p. 802)

In the context of the current study, I explore physics teachers’ intentions in relation to student solutions, when interpreting and providing feedback on student responses. The implication of the Redish (1994) argument is that in a situation where the teachers consider, in their instructional planning, only what they expect students to learn and its presentation, they will have no interest in students’ pre-instructional knowledge. In such teaching, there may be no interpretation and judgment of students’ thoughts, interactions, and understanding of the content. The implication is that such a teacher will lack an understanding of individual student predispositions in cognition or instruction and focus predominantly on achieving prescribed teaching-learning outcomes. This perspective is more oriented towards a content centered perspective, viewed as traditional teaching.

On the other hand, Redish argues that it is possible for teachers to place an emphasis in the classroom on engaging students’ pre-instructional knowledge, in order to understand and interpret students’ interaction with and solutions to theoretical problems they pose. These teachers may have an approach that focuses predominantly on maintaining student participation in a constructivist dialogue as the index of student learning. Redish sees such teaching as oriented towards advancing student thinking or as learner centered.

2.2 Issues in learning the topic of motion

This study is an exploration of aspects of physics teachers’ knowledge about teaching linear motion. The literature describing student common sense preconceptions or
misconceptions of motion and the use of the kinematics formula will be reviewed for this study, below.

2.2.1 Misconceptions

An exploration of the teacher responses or feedback on student understanding is a major focus of this research. There have been investigations on many students’ misconceptions and conceptual change in the physics context. For example, Duit (2006) lists an extensive bibliography on students’ ideas and teachers’ misconceptions in science education.

Researchers suggest many students face cognitive dissonance between their prior knowledge (including common sense conceptions in the area of motion) and the targeted scientific concepts (diSessa, 1993; diSessa & Sherin, 1998; Driver, Guesne & Tiberghien, 1985; Driver, Squires, Rushworth & Wood-Robinson, 1994; Sherin, 1996, 2001; Tuminaro, 2004; Tuminaro & Redish, 2007). These contradictions which are typically referred to as preconceptions or misconceptions (Magnusson et al., 1999; Prescott, 2004; Prescott & Mitchelmore, 2005; Shulman, 1986), are “a common feature of science learning, [and] are typically favoured over scientific knowledge”, and make scientific concepts difficult to learn (Magnusson et al., 1999, p. 105). In motion, students often believe that if an object is pushed with a constant force “this produces constant motion; and that if the pushing force ceases there is a ‘force’ in the moving object which keeps it going but which gradually gets used up and then the object stops” (Driver et al. 1994, p. 154). This is a logical inference of students about the real friction-filled world that contradicts the scientifically accepted explanation.

Duit and his colleagues (2007) concluded that throughout the process of learning physics concepts, the specific difficulty of conceptual change “appears to be that usually students’ preinstructional conceptions about phenomena are deeply rooted in everyday experiences and are therefore in stark contrast to physics conceptions” (p. 606). A major problem for students in understanding the underlying concept(s) and principles of physics seems to be “radical idealization and decontextualization, [and] the reduction to pure phenomena accompanied by particular mathematical modeling” (p 606).

In the current study, teachers’ feedback to students was analysed to understand and categorise teachers’ beliefs and perspectives, for the skilled knowledge they reveal of students’ naïve every day conceptions of forces and linear motion. This study also
identified where teachers’ responses were restricted to pure scientific phenomena and motion problem solving.

From the constructivist perspective, Clement (1983, 1994), diSessa, (1993), Duit et al. (2007), Magnusson, Templin and Boyle (1997), McDermott (1984), Smith, diSessa and Roschelle (1993) have argued that teachers should not attempt to extinguish misconceptions, as misconceptions can continue to evolve and change and result in desired scientific knowledge. In the topic of mechanics, Duit and his colleagues (2007) showed that “elicitation of students’ own ideas helps to contrast their intuitive views with the scientific notion of force” (p. 617). Clement (1994) also attempted to make a bridge between naïve physics and physics problem solving. He found that non-formal reasoning, which he called “physical intuitions and imagistic simulations” (p. 204), has an important function in expert thinking during the physics problem solving. While Clement did not focus on the connection between non-formal reasoning and formal definition of the relationships in equations, Sherin (1996, 2001) argued that intuitive physics is an important part of the conceptual basis to (mis)understanding equations to solve problems. In a study conducted on third year engineering students, Sherin (2001, p. 488) gave the students the following problem about a Shoved Block (see Figure 2.3).

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)


Figure 2.3: Shoved Block task.

The correct answer is that the heavier and lighter blocks travel precisely the same distance, an explanation of which is analogous to Galileo’s thought experiment with the free falling feather and cannon ball. However, students in Sherin’s study were
dissatisfied with this counterintuitive result, leading them to invent their own brand of physics and write a completely new equation: \( \mu = \mu_1 + C \left( \frac{\mu_2}{m} \right) \), where \( m \) is the mass and \( \mu_1, \mu_2, \) and \( C \) are constants. Sherin’s solution was:

The heavier block should travel less far because it presses down harder on the table and thus experiences a stronger frictional force slowing it down. The alternative intuition was that the heavier block should travel farther because it has more momentum and is thus harder to stop. In fact, it is because these two effects precisely cancel each other that the heavier and lighter block travel the same distance. (p. 489)

Sherin (2001) concluded that the above equation invented by students could not be explained in terms of the manipulation of known equations or even in terms of derivation from given principles, and was based on intuitive understanding. Based on diSessa’s (1993) notion of sense-of-mechanism (explained below), Sherin referred to these intuitions as symbolic forms which complement more formal knowledge in students’ thinking. Sherin’s symbolic forms are based on conceptual schemata, where the structure of a schema corresponds to an understanding of conceptual relations or structure in the real-world. These symbolic forms also allow one to: “(a) construct expressions, (b) reconstruct partly remembered expressions, (c) judge the reasonableness of a derived expression, and (d) extract implications from a derived expression” (Sherin, 2001, p. 499).

diSessa (1993) has described an epistemology of physics learning through elaborating on intuitive physics knowledge as being a “physics sense-of-mechanism” notion which ultimately can explain physical phenomena and can help the learning of school physics. This notion implies “a sense of how things work, what sorts of events are necessary, likely, possible, or impossible” (diSessa, 1993, p. 106). In relation to this notion, he stated that a novice physics learner’s knowledge is not a tightly connected structure, but it comprises a “knowledge-in-pieces” structure. To understand the development of physical causality, the novices use their “intuitive physics”, which is sometimes labeled as “preconception, misconception, or alternative conception” (diSessa, 1993, pp. 106-107). While this labeling may help to understand and to broadly identify students’ difficulties in seeking scientific understanding, it is problematic for documenting progress in students’ learning. diSessa argues that intuitive physics represents “a coherent, even theoretical, view of the world, … [which] does not need to
be replaced so much as developed and refined” (p. 109). To make a connection between the experientially acquired knowledge of the physical world and the expert scientific understanding of physics and to identify the primitive elements of knowledge involved in sense-of-mechanism, diSessa (1993) described 29 phenomenological primitives or p-prims, for example, a force and motion p-prim in which force is a mover, dying away. These p-prims constitute early perceptual pattern knowledge and are connected as a network so that one may activate other(s). They are “phenomenological in that, they are responses to experienced and observed phenomena” (Resnick, 1993, p. 102). The p-prims are “linked to, [and] cued by, those phenomena rather than being general or abstract. They are primitive in the sense that they are self-evident to their holders, requiring no further explanation” (Resnick, 1993, p. 102). The implication is that the challenging of teaching-learning of a scientific understanding of physics is the transformation (rearrangement and organisation) of the p-prims, the component parts of the intuitive sense of mechanism.

The review by Gunstone and Watts (1985) of students’ conceptions about force and motion in different countries including Britain, Norway, France, Belgium, America, and Australia reported that a common student belief was that “constant motion requires a constant force” (p. 91). Some other widely held conceptions of motion included, “the amount of motion is proportional to the amount of force”, and “if a body is moving there is force acting on it in the direction of motion”. The authors refer to these conceptions as “intuitive rules”, not misconceptions (pp. 93, 95). They concluded that students themselves have “ideas about force and motion before they enter science classrooms”, and students’ views and the scientists’ views about force and motion “may not be in opposition to each other, … [and] what seems to be conflict might not be conflict” (p.p. 98-99). They suggested that teachers should discuss every day observations of motion and force with students and give more time for students to verbalise their views to consider alternative interpretations. This constructivist approach they claim is likely to be more successful in modifying students’ views of force and motion than confronting their conceptions as simply ‘incorrect’ and attempting to replace them with the ‘correct’ views. Gunstone and Watts’ review suggests the importance of investigating teachers’ awareness of, and responses to, students’ intuitive reasoning.

In a similar vein to the above literature, Magnusson et al. (1999) envisage instruction with a conceptual change orientation as accruing as “students are pressed for
their views about the world and consider the adequacy of alternative explanations”. As teachers facilitate “discussion and debate necessary to establish valid knowledge claims”, they facilitate “the development of scientific knowledge by confronting students with contexts to explain that challenge their naïve conceptions” (pp. 100-101). This version of research suggests that such physics teachers in the current study could respond to student solutions to a linear motion task in a manner which confronts students’ common sense conceptions.

Prescott and Mitchelmore (2005) reported on Year 12 NSW students’ misconceptions about projectile motion in the context of mathematics. They found that the students’ misconceptions about the path of a ball dropped from a moving carrier was mostly that the ball would drop straight down. In a wider study including teachers, Prescott (2004) had found that teachers themselves seemed to hold many of the same misconceptions about projectile motion that their students. However, they did not investigate teachers’ awareness of students’ misconceptions. Prescott and Mitchelmore, in contrast to Gunstone and Watts (1985), and diSessa (1993), suggested that misconceptions should be eliminated in teaching projectile motion. The work of diSessa (1993), Gunstone and Watts (1985), and Sherin (1996, 2001) has informed my exploration of teacher feedback on students’ solutions to linear motion tasks.

In the current study, physics teachers’ intentions in responding to students’ misconception(s) were examined. The study investigated teacher attention to students’ phenomenological perceptions in their responses to motion tasks. The teachers, in response to students’ attempted solutions, might seek to present the student with the correct answer, or seek to develop existing student understanding and misunderstanding or preconceptions.

2.2.2 Using the kinematics formulae

Both physics and mathematics knowledge are prerequisites for learning kinematics which is a basic concept, but part of the topic of motion. As previously noted, whilst pure mathematics seeks abstract representation, physics describes fundamental relationships between physical quantities (Manouque et al., 2006). In using the mathematics in physics, research at both the secondary and tertiary levels by Lawson and Mc Dermott (1987), McDermott (1991), McDermott, Shaffer and Somers (1994), Pride, Vokos and McDermott (1998), Redish (1994), Redish and Steinberg (1999), Shaffer and McDermott (2005), Sherin (1996, 2001), Tuminaro (2004), and Tuminaro
and Redish (2007) showed that students (in the classroom) are often unable to interpret or explain the meaning of their own algebraically derived solutions to set problems. These authors have argued that student success in the derivation of correct numerical answers does not necessarily imply a corresponding level of conceptual understanding of physical principles. Given the above studies, it can be argued that difficulties in physics problem solving may indicate a lack in the students’ understandings of how the mathematics formulae are understood and deployed in specific physics contexts.

For instance, it has been noticed that students’ misconceptions occurring during physics problem solving is due to interpreting mathematical terms (in a physics problem) using everyday language interpretations, not mathematical interpretations. As stated by Hale (2007), “even though students understand the requisite mathematical concepts, they still have misconceptions concerning the interpretation of mathematical terms in a physical setting” (p. 28). Hale (2007) also suggested that while both the “mathematicians and physicists believe that when people communicate mathematics using algebraic symbols, communication is precise and unambiguous” (p. 28), using mathematical symbols, as well as, physics abbreviations makes (for) a great deal of ambiguity, which leads to many misconceptions in physics problem solving (Hale, 2007).

With respect to the use of mathematical equations in physics, Sherin (2001) proposed that a “conceptual schema” is an idea which is expressed in an equation in a symbolic form. Sherin (1996, 2001) developed a specific framework to assist students to learn how to use mathematical symbols in physics equations. Sherin’s framework comprises a vocabulary of elements which “associates a simple conceptual schema with a pattern of symbols in an equation” (Sherin, 2001, p. 479). The arrangement or pattern of symbols in a symbolic form, called a “symbol template”, is the knowledge element which underpins the structure of the mathematical expression and specifies how that idea is written in symbols. For instance, two common symbolic templates are “\(= \triangleleft\), and \(\triangleleft + \triangleleft + \triangleleft \ldots\)” The former is “a template for an equation in which two expressions are set equal”, while the latter is “a template for an expression in which a string of terms are separated by plus signs” (Sherin, 2001, p. 490). When problem solvers are aware of symbolic forms, Sherin proposed, they “can take a conceptual understanding of some physical situations and express that understanding in an equation” (Sherin, 2001, p. 482).
To investigate student understanding of kinematics variables, namely distance, velocity and acceleration, Hale (2007) conducted a videotaped study of 121 students at a medium-sized public university on the West Coast of the United States. Although it was assumed that most students had some experience with the kinematic variables (e.g. velocity), their personal understanding of kinematic variables might be incomplete or erroneous. Hale (2007) found that these students chose an (incorrect) conclusion based on their everyday language, which was different to their (correct) conclusion based on their mathematical knowledge. They surprisingly still chose their incorrect conclusion, even though using calculators led them to the correct conclusion with the actual physical situation. Hale concluded that “students’ difficulties interpreting graphs of kinematic variables were not necessarily due to simple confusion when reading the axes or a lack of understanding of the meaning of the slope of a graph” (p. 43). The students’ misconceptions (based on their personal experiences and common language) made them “use these conceptions incorrectly to solve mathematics and physics problems” (p. 43).

Whilst examining students’ understanding of kinematics equations Sherin (2001) found that students often used the equation \( v = v_0 + \frac{1}{2} at^2 \) instead of \( v = v_0 + at \), when they were solving kinematics problems. He concluded that students could understand the “base + change” symbolic form, but they confused the second part of the equation, that is, \( at \), as they mixed up this equation with the displacement equation: \( x = x_0 + v_0 t + \frac{1}{2} at^2 \). In this regard, Sherin believed that students had difficulty in understanding the concept of “change” involving two elements. The students did not understand the change entity \( \frac{1}{2} at^2 \) or the correct units of the second term (Sherin, 2001). The “change” is comprised of a product of an intensive quantity and an extensive quantity. “An intensive quantity is an amount of something per unit of something else. An extensive quantity is a number of units” (p. 536). Using Sherin’s framework, students could be introduced to “\( at \) in terms of the intensive – extensive form” (p. 520). Sherin developed a vocabulary of elements (symbolic forms) to interpret and describe this equation \( v = v_0 + at \). Each symbolic form has two components: symbolic template and conceptual schema (Table 2.1).
Table 2.1

Two symbolic forms used in a kinematics equation \( v = v_0 + at \)

<table>
<thead>
<tr>
<th>Conceptual Schema</th>
<th>Description of Conceptual Schema</th>
<th>Symbol</th>
<th>Identification of Symbol Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base + change</td>
<td>Two terms contribute to a whole but play different roles. One is a base value; the other is a change to that base.</td>
<td>( \square \pm \Delta )</td>
<td>Identification of one term with a base or initial value. The second item corresponds to a change that occurs through time or across cases.</td>
</tr>
<tr>
<td>Intensive – extensive</td>
<td>A product of an intensive quantity and an extensive quantity.</td>
<td>( X \times Y )</td>
<td>Common when the intensive quantity is a density or rate. Utterances and examples could involve explicit comments about the physical entities ( x ) and ( y ), and frequently the units left out will be stated.</td>
</tr>
</tbody>
</table>


In the current study, the description of symbolic forms in Table 2.1 was useful in analyzing physics teachers’ explanations of their teaching approach when introducing formulae, such as, \( v = v_0 + at \), and when providing feedback on student responses.

2.3 Factors affecting problem solving

As well as exploring teachers’ interpretations of, and feedback on a range of students’ solutions to motion tasks, the study also investigated the teachers’ responses to the challenge of describing their approach to solving standard textbook and non-standard motion tasks. It is necessary here to consider the literature related to the factors affecting physics problem solving, particularly the difficulties in understanding and
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solving a task (see section 2.3.1) and bridging the gap between using formulae and problem solving strategies (see section 2.3.2).

2.3.1 Difficulties in understanding and solving a problem

Research on physics problem solving has mainly focused on the steps used by the problem solver in solving problems. Early studies on physics problem solving were conducted to identify the differences between experts and novices (Chi, Feltovich & Glaser, 1981; Larkin, 1981, 1983; Larkin, McDermott, Simon & Simon, 1980; Larkin & Reif, 1979; Reif & Allen, 1992; Simon & Simon 1978). For example, Larkin et al. (1980) observed that novices tend to “backward chain,” whereas experts tend to “forward chain” when solving problems. Novices tend to attack the problem by determining what the end goal is and then working backwards from the end goal toward the initial conditions that are given in the problem statement. In contrast, the expert tends to start with the initial conditions given in the problem statement and work toward the end goal. This is surprising because backward chaining is generally thought to be a sophisticated problem solving technique in motion tasks.

Savage and Williams (1990) introduced a physics problem solving model in mechanics, followed by Heller and Heller (1995) who proposed that the logical physics problem solving model consisted of five stages:

1. Focusing on the problem,
2. Explaining the physical principles,
3. Planning the solution,
4. Carrying out the solution, and
5. Evaluating the answer.

As previously mentioned, Larkin (1983) described a principle-based view to explain the problem solver’s approach to using equations in physics, which is strictly guided by physics principles and originates from their physical identification with a particular situation. In a similar vein, Nathan, Kintsch and Young (1992) described student difficulties in terms of algebra word-problem comprehension. They described the difficulties based on three components: an understanding of the problem statement, a qualitative understanding of the particular situation, and a quantitative understanding of the particular situation that captures the algebraic problem structure (equations). However, it seems that these models are normative, rather than descriptive. That is, the
authors seek to idealize student thinking, but they do not report actual dialogue with students or teachers in problem solving practices.

When Tuminaro (2004) and Tuminaro and Redish (2007) developed a cognitive framework for analyzing and describing students’ use and understanding of mathematics in the context of physics, they identified the kinds of mistakes made in the process. They conducted a study on first year introductory physics students at the University of Maryland. They employed Sherin’s symbolic forms (1996, 2001) and developed a theoretical framework regarding “a vocabulary (ontological classification of cognitive structures) and grammar (relationships between the cognitive structures) for understanding the nature and origin of students’ use of the mathematics in the context of physics” when solving physics tasks (Tuminaro, 2004, p. 120). More importantly, they introduced ‘epistemic games and frames’ to address the grammar of the process components of students’ mathematical thinking and problem solving in the context of physics. In the context of their study sample, they identified six different games that students used in physics problem solving: “Mapping Meaning to Mathematics, Mapping Mathematics to Meaning, Physical Mechanism Game, Pictorial Analysis, Recursive Plug-and-Chug, and Transliteration to Mathematics” (2004, p. 119; 2007, p. 5). They propose that conceptual understanding of a physical situation can start in Mapping Meaning to Mathematics, and then is interpreted into physics equations. In Mapping Mathematics to Meaning, a physics equation is used to make sense of a particular physical condition or physics problem. In the Physical Mechanism Game, a physical sense of system (for a particular physical condition or physics problem) is used, based on an intuitive conceptual understanding. An external representation is created in Pictorial Analysis that captures the spatial relationship between the various (relevant) parts in a physics problem. Recursive Plug-and-Chug is engaged with plugging numbers or symbols into physics equations, in a recursive approach, to form an answer. And lastly, in Transliteration to Mathematics, worked examples are used to produce a solution without developing a conceptual understanding of the worked example.

The above information about different approaches used by students implies that teacher awareness of the underlying concepts of Tuminaro’s epistemic games is important for students’ learning in a problem solving setting. In the current study the vocabulary and grammar of teachers’ written feedback and in their teaching was examined for an awareness of epistemic games.
In the context of the current study, teacher anticipations or diagnosis of the source of students’ difficulties as well as the quality of teacher explanation in response to student difficulties (for example, giving meaning to the mathematics versus rote manipulation epistemic games) was also examined.

2.3.2 Bridging the gap between using formulae and problem solving strategies

In the practice of motion problem solving, usually the problem solver reads the problem and writes the known (given) and unknown (needed) entities. Then, they will recall the equation(s) from memory (which contain these various entities) and start to arithmetically manipulate the equation(s) to find a route from known (given) quantities to unknown (needed) quantities. The student may know the route that the solution takes and how to use the required equations to follow the route (and steps) in reaching the solution (to find the unknown quantities), however the student does not necessarily understand why an individual equation has its own form. As a simple example, the student may consider the following problem:

*A driver starts driving his car from a stopped position. If the car acceleration is 10m/s², how long does it take to reach a velocity of 30 m/s?*

Here the student is given the initial velocity \(v_0 = 0 \text{ m/s}\), the acceleration \(a = 10 \text{ m/s}^2\), the final velocity \(v = 30 \text{ m/s}\), and is asked for the time. Once the equation \(v = v_0 + at\) is recalled, the question can be simply solved for time. However, the student solution does not reveal in what sense the equation \(v = v_0 + at\) is understood by a student. It is possible that the student cannot extend their knowledge beyond the conditions under which this equation is used. They might not be able to derive the equation from physical principles.

Sweller (1999) proposed, like Sherin (2001), that dealing with a simple kinematic equation, for example \(x = vt\), where understanding is relevant, imposed a heavy load on working (short term) memory. Sweller (1999) and Ward and Sweller (1990) analysed the working memory requirements associated with the skilled knowledge of this equation and defined 11 logical elements involved in this simple equation, where an element is defined as “anything that needs to be understood and learned” (p. 24), (see Figure 2.4).
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1. $x = \text{distance travelled}$
2. $v = \text{average speed}$
3. $t = \text{time}$
4. Speed is defined as the number of units of distance travelled in a single unit of time.
5. Multiplying the number of units of distance travelled in a single unit of time by the number of units of time equals the distance travelled.


**Figure 2.4:** Elements involved in the equation $x=v \times t$.

To skillfully use this equation in a physics context the students need to simultaneously and sequentially manipulate all of the above elements in their working memory. Skilled knowledge in this sense, is the ability to make required connection(s) between elements (element interactivity). In rote manipulation however, skilled knowledge is absent, making problem solving difficult. Therefore, in the domain of problem solving strategy involved with using kinematics equations, understanding the number of elements and the degree (level) of element interactivity is important. Sweller (1999) proposed that “high element interactivity results in difficulty in understanding the material [equation] because of the large number of elements that must be held in working memory simultaneously, while the total numbers of elements require extensive learning periods”. In the mathematics classroom, to understand the equation of $x = v \times t$, only five elements — $x$, = (equal sign), $v$, multiplying, and $t$ — have interaction with each other. The mathematical problem solver has to manipulate two values, in order to derive the unknown variable without focusing on any meaning or unit for $x$, $v$, and $t$. In physics, the problem solver must not only understand algebraic elements, but also their symbolic associations with a physical quantity. In the case of rote manipulation of symbols in a physics classroom, students follow mathematical use, which does not lead
to an understanding of the physical entities or their units. Sweller (1999) proposed that a
problem state is considered as a single entity (as a schema) by an expert problem solver,
rather than a collection of several elements in working (short-term) memory. A
cognitive construct he suggests, allows “multiple elements of information” to be treated
as a single entity or “schema” and “held in long-term memory” (Sweller, 1999, pp. 10-
11). In the context of the current study, Chi et al. (1981), and Larkin (1983) suggested
that experts have several schemata which are directly associated with physics principles,
allowing them to recall a specific schema to solve a specific problem. For example, in a
problem involving force, the expert uses a ‘force schema’ that corresponds to the
physics principle that the total force on a system is the product of the system’s mass and
its acceleration (F = ma), namely Newton’s second law of motion.

The student using such principle-based schemata, based on physical principles,
where the structure of a schema corresponds to the steps involved in solving a problem
is described by some literature (e.g. Larkin, 1983) as having skilled knowledge
emphasizing a meaningful problem solving strategy.

2.4 Relationship between key components of teacher knowledge and teaching
approach

This study has a major focus on exploring teacher intentions and beliefs about problem
solving and various aspects of teachers’ PCK in the particular topic of linear motion. As
mentioned above, PCK comprises multiple aspects of a teacher’s teaching practice. In
this study, some aspects of physics teachers’ PCK will be examined, including: teacher
interpretations of, and feedback on students’ problem solutions as well as their beliefs
about the practice of teaching and learning, and their CK in linear motion. What follows
is a review of the literature about teacher knowledge and beliefs about student
understanding of science topics (Gess-Newsome & Lederman, 1999) (see section 2.4.1),
and teacher knowledge and beliefs about successful teaching of physics (see section
2.4.2). Teacher knowledge of the content and teachers’ responses to the learning
demands of their students are two important features of PCK (Loughran et al., 2001).
Section 2.4.3 reviews the literature about teachers’ content knowledge and feedback on
student difficulties.
2.4.1 Teacher knowledge and beliefs about student understanding in particular content areas of physics

Teacher knowledge and beliefs about students’ understanding of physics topics both reflect and support their teaching purposes and intentions. In the context of the current study, I focus on exploring teacher purposes in their interpretation of student solutions to specific linear motion tasks.

Two important aspects of PCK found by Magnusson et al. (1999) – teachers’ awareness of students’ difficulties and teachers’ responses to these difficulties – have not been carefully studied. Physics instructors may be assumed to have a view of how students learn. This presumably includes an understanding of the current knowledge and ability of their students, and a skilled knowledge of how to actively engage students in learning, through designing appropriate thinking tasks, which includes developing their skills in manipulating and understanding the core concepts which could result in deep, as opposed to surface, learning. Gerace and Beatty (2005) propose that teachers should use problem tasks in a manner that induces student engagement in conceptual, quantitative, and comparative reasoning, and discourage equation manipulation and means-ends analysis. They see the role for the physics teacher as being a learning guide rather than a presenter of physics content and expert problem solver. They see the former in a dynamic learning classroom engaged in a bidirectional communication process with active students. They consider teachers in the latter role as engaged in one-way instruction in traditional physics teaching, through problem solving and rote manipulation of the equations and numeric values. They proposed that physics teachers who take the former position understand individual students’ misconceptions and constructions, as well as their own constructions and representations in the particular domain of physics instruction.

Hestenes, Wells and Swackhamer (1992) suggest that, not only are teachers expected to teach what they know but also how they know it and how they value it. But to engage students in these cultural, historical and psychological aspects of a teaching conversation they require “technical knowledge”, which includes the knowledge of how to elicit and work with students’ common sense knowledge and beliefs or their preconceptions (p. 142). Hestenes and colleagues (1992) argued that, in kinematics, a students’ discrimination between position, velocity, and acceleration, as well as the recognition of the vectorial nature of velocity and acceleration, require elaboration in
conversation with students about their common sense beliefs. Another common sense misconception is that “motion implies active force” derived from this syllogism: “Every effect has a cause. Motion is an effect. Therefore motion has a cause”. Hence, when velocity and acceleration are not distinguished, the concept of “velocity is proportional to force” is not obviously distinguished from “acceleration is proportional to force” (Hestenes, et al., 1992, p. 144).

Berg and Brouwer (1991), in a study on twenty high school physics teachers, concluded that physics teachers were aware of only a few common difficulties their students had in achieving a formal understanding of force and motion. Furthermore, about one-third of their sample of teachers lacked the relevant physics knowledge necessary to help their students overcome these difficulties. Smith and Neale (1989, 1991), in a study on ten primary school teachers who attended a summer program that focused on conceptual change teaching in science, reported that their in-service program could improve teachers’ knowledge of students’ difficulties; however this research did not necessarily provide evidence of the appropriateness of the teachers’ response(s) to their students’ difficulties.

Krajcik and Layman (1989) reached a similar conclusion in relation to teacher knowledge of heat, energy and temperature. Magnusson (1991) and Magnusson et al. (1999) argued that a lack of insight into student difficulties could limit the development of the skilled knowledge of constructivist teaching amongst physics teachers.

In the domain of teachers’ insight into students’ difficulties involving a study of the evolution of PCK in prospective physics teachers, Veal, Tippins and Bell (1999) showed that through teaching experience teachers could develop skilled knowledge of “possible or foreseeable mistakes and/or misconceptions that students make”, which was more easily recognisable when the teachers were introduced to the concept of PCK. They were observed to change their instructional approach “to include a step by step explanation of the maths involved in solving homework problems” (p. 20).

Stump (1999, 2001) reported that both pre-service and in-service teachers typically introduce students to the mathematical meaning of slope of a line graph when teaching the slope concept. In relation to teacher concern with student difficulties Stump (2001) found that “the specific student difficulties they [teachers] identified focused on procedures rather than conceptual notions” (p. 210). In the current study of teachers
responses to student solutions their disposition to focus on procedures or concepts was studied.

There remains a gap in the literature in the area of exploring teacher specialised knowledge and intentions. In this study, it is that gap – the teachers’ discursive practices when teaching linear motion – which is addressed.

2.4.2 Teacher knowledge and beliefs about teaching physics

As this study was concerned with exploring teacher thinking or beliefs about teaching and providing feedback on student solutions when solving motion tasks, it is important to review, firstly, teacher knowledge and then beliefs about teaching and learning science and physics generally.

Teacher knowledge and beliefs about teaching and learning science and physics

During the 1990s, a large number of studies focused on the links between science teachers’ beliefs and their daily classroom practices. Among these, Tobin and colleagues (e.g. Tobin, Kahle & Fraser, 1990; Tobin, Tippins & Hook, 1994; Tobin & Tippins, 1996; Tobin, 1998) explained that if the science teacher defines their role as identifying and presenting the most important facts and assisting students to memorize them, then their practice is mainly based on an approach which helps students memorize procedures (rote memory), recall the information and manage procedures to reach the conclusion. In this case, when the teacher’s attitude towards understanding was regarded as making connections between facts, “a physiological process over which the teacher had no control”, then students had to “memorize a critical mass of facts and the interconnections”, and “associated understandings were thought to emerge”, leading to the conclusion that the “teacher’s failure to build a mental model for understanding made it difficult for him to alter his practices to assist students to build understanding” (Tobin, 1998, p. 135). These authors concluded that the teacher’s beliefs and propositional knowledge about teaching could reflect on the teacher’s explanations of their understanding of learning and the teacher’s teaching strategies to enhance understanding.

On the importance of social interaction with students, and in an attempt to investigate teachers’ metaphors when teaching science, Tobin, Kahle and Fraser (1990) reported two distinctive experienced teaching styles: that of being a leader and that of being an entertainer in dealing with the students. Later Tobin and LaMaster (1995) conducted a collaborative study on a novice science teacher to help her to build a mental
model consistent with her beliefs about the nature of knowledge and the learning process in students. Throughout an evolving process, this science teacher developed a teaching metaphor as that of being a social director. The teacher, like a hostess, believed she should provide an attractive invitation for students to come to the class, to have fun (in learning), not to disrupt the learning of others, to be courteous to the teacher and to evolve a new culture. This metaphor extended not only to classroom management but also to her assessment of students. These two studies showed the potential significance of teachers’ beliefs about teaching in building the mental models for teaching and learning science in classrooms. Metaphorical views such as being a guardian of the discipline, along with a need to cover the prescribed content, and to prepare the students for the exams and the next educational level, and time-constraints are associated with belief in the importance of retaining traditional practices (Tobin & McRobbie, 1996). These metaphors in some instances could overwhelm a teacher’s progressive belief about student understanding and teaching practices. For example, Tobin, McRobbie and Anderson (1997) reported that, while a beginning physics teacher believed in a social constructive view of teaching and learning, when it came to classroom practice and understanding, the teacher and his students accepted knowledge as right or wrong based on a metaphoric authority of the discipline. Though the classroom culture was in favour of students’ autonomy in their learning, the metaphoric goal of the teaching was directed towards learning correct answers and covering the content in a specified time in order to succeed in tests and examinations.

In a longitudinal study on the importance of the facilitative role of science teachers in ‘tomorrow’s’ schools, Tobin, Tippins and Gallard (1994) argued that science teachers’ personal beliefs play an important role in shaping their teaching practices and instructional behaviour, as “[t]hey are useful in determining whether particular actions are legitimate in the culture of the science classrooms in which they operate” (p. 55). The authors believed that teachers’ beliefs evolve over time and “are pervasive in the classroom and influence the nature of teacher roles, planning and decision-making processes, and ultimately the curriculum” (p. 61). Tobin (1998) concluded that an understanding of teachers’ beliefs can provide “insight into how teachers can conceptualise their goals and roles and translate what they know into professional practice” (p. 148).
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Through the historical evolution of constructivism, the study of the ways in which teachers and learners made sense of their role and goals has received a strong impetus. In the metacognitive domain of science learning, Tobin (1998, p. 131) observes, if students are to believe that they should be asking “What and why am I doing?” and “What do I already know and what else do I need to do/ know?”, teachers will be asking themselves “How does my teaching promote the types of good learning behaviours that I have identified as appropriate for students?” and “How can I act with students to develop an appropriate level of challenge in science class work?”

With respect to the relationship between teacher knowledge and beliefs, Peterson, Fennema and Carpenter (1991) stated, when conducting research on the knowledge of mathematics teachers, that:

> We are struck both by the influence of teachers’ knowledge on their thinking about instruction, learning and assessment, as well as by the pervasive influence of teachers’ beliefs about students’ knowledge; by the way in which teachers’ thinking was influenced both by their beliefs and by their knowledge; and by the interconnections that seem to exist between knowledge and beliefs in the teachers’ minds. (pp. 60-61)

The assumption in this study is that knowledge and belief are intimately related and mutually informing. With a particular focus on the role of mathematics in physics, Mulhall and Gunstone (2008) conducted a qualitative study involving extensive semi-structured interviewing and observation of the teaching practice of two groups of upper secondary physics teachers. These groups included five teachers with ‘traditional approaches’ and five teachers with ‘conceptual approaches’. The study explored the linkage between teachers’ beliefs and their teaching practice. They reported that there was seemingly a uniform link between teachers’ beliefs and the teaching approaches in traditional group, but not in the conceptual change group. Teachers in the traditional group “saw physics as discovered, close approximations of reality, while the conceptual change teachers’ views about physics ranged from a social constructivist perspective to more realist views” (p. 435). A significant conclusion of these researchers was that most of the teachers in both groups, “did not appear to have given much thought to the nature of physics or physics knowledge, nor to the role of mathematics in physics” (p. 435), and “the teaching practices of these two groups were more strongly linked to their views about the nature of physics teaching than to their view about physics” (p. 456).
Teacher knowledge and beliefs regarding problem solving in physics

As explained previously, the focus of this study is on investigating teacher thinking and beliefs about teaching and learning linear motion. Two aspects of teachers’ PCK are involved here in two equally important tasks – devising representations and responding to student need in various ways including setting up learning environments or activities. Shulman (1986) and Magnusson et al. (1999) characterised representations as expert teachers’ powerful knowledge of the ways of symbolising a concept in a specific topic using a particular metaphor or simile. The weakness and strength of a particular representation, as well as a teacher’s ability to introduce alternative representation(s) would help students attain the teacher-intended meaning about the topic or concept. They also consider that expert teacher’s responses that anticipate and develop students’ understanding of ideas, such as problem solving, demonstrations or experiments, include not only skilled knowledge of how to reflexively direct and perform enactments with and for the students, but also skilled knowledge of the specific value and purpose of each.

Gerace and Beatty (2005) argue that experts have coherent, organized and structured knowledge, whereas the novices have sparse, disconnected knowledge. They found the expert teacher problem solver in their typical instruction, often explicitly models quantitative analysis for students, leaving the students to develop the other skills on their own, of which the teacher has no understanding.

In physics instruction, problem solving is an established language game for improving student understanding of any physics task including the linear motion topic (Wittgenstein, 1975). Problem solving is a process, which depends largely on the extent of knowledge, as well as the organisation of the possessed knowledge. However, some literature (e.g. Redish, 1994; Gerace & Beatty, 2005) suggests teaching physics through problem solving in traditional physics instruction seems to be ineffective in promoting learning of the physics concepts involved in real life contexts. Problem solving is usually employed in physics classrooms through worked examples, and then through homework problems to give the students practice for the end of course exams, in the same mode. Teachers also appraise their own competence as teachers of physics by their students’ performances in these exams, which are used for entry to undergraduate and postgraduate courses. A common belief among teachers and students is that success in the exams (at different levels) indicates effective teaching and learning. However,
research instruments have been developed to assess the conceptual understanding of basic concepts of introductory mechanics, such as the Force Concept Inventory (CFI) (Hestenes et al., 1992), and a large body of research indicates that this is not the case (Hake, 1998; McDermott, 1991, 1993; Redish, 1994; Redish & Steinberg, 1999). These studies have argued that problem solving in traditional physics instruction only increases students’ facility in answering problems practiced to pass the final exams. The authors suggest the traditional approach is not effective for most students in developing understanding of the principles of physics for the application of learnt paradigms in new contexts, solving non-standard problems, or to progress expertise and mastery in physics, generally. The current study explores teachers’ thinking about teaching and learning of motion through analyzing their written comments and beliefs. Their intention, for example, to use traditional and/or constructivist teaching approaches for standard and non-standard tasks is examined.

Redish (1994) concluded that teachers teach students as they themselves solve the problem, and do not consider students’ perspectives for learning content. He described this as “the dead leaves model” (p. 799):

- Writing the equations after the teacher or from the book.
- Memorizing the equations
- Doing lots of problems to recognise which formula is suitable for which question
- Passing the exam by using similar formulae for similar questions
- Removing the information from the brain after the exam to make way for the next materials

He concluded that it is as if physics were a “collection of equations on fallen leaves” One might hold \( s = \frac{1}{2} gt^2 \), another \( F = ma \), and a third \( F = -kx \). These are each considered as of equivalent weight, importance, and structure. “The only thing one needs to do when solving a problem is to flip through one's collection of leaves until one finds the appropriate equation. I would much prefer to have my students see physics as a living tree!” (p. 799). In the current study physics teachers’ beliefs and intentions for teaching and providing feedback on student difficulties in solving a linear motion task will be examined, considering the element of ‘the dead leaves model’ explained above.

Exploring teacher feedback on a student difficulty is a major focus of this research. In characterising teachers’ feedback there is a need to consider active engagement with
the students’ prior knowledge of the subject material and students’ responses. Additionally, presenting feedback to students requires an understanding of their psychological and social dispositions. The teachers’ knowledge and beliefs about problem solving is also considered to be central in physics teaching. For example, rather than teaching solving problems in a rote way (following the rule ‘from known to unknown’), researchers (e.g. Redish, 1994) suggest teachers should have beliefs and commitment in designing and delivering instruction using the twin resources of students’ prior knowledge and students’ individual dispositions. This requires an ongoing dialogue between the student’s knowledge and the teacher interpretation of students’ needs. This form of logical investigation in this research arises not from an interest in finding a causal connection, but from an urge to understand the basis or essence of teachers’ thinking, intentions and purposes for teaching and understanding problem solving. Gerace and Beatty (2005) speaking to teachers of this challenge believed that,

Rather than “teaching”, we find ourselves engaged in the design and management of beneficial educational experiences, guiding students as they engage in an iterative, difficult, and often frustrating process of sense-making knowledge-organising. Often, we must work hard to overcome the misconceptions and naïve understandings students begin with. We must also repeatedly revisit ideas as students extend their understanding into new contexts and build increasingly sophisticated knowledge structures. (p. 4)

In a similar vein, Dufresne, Gerace, Mestre and Leonard (2000) in their study in high school and college level physics classrooms, the ASK-IT/Assessing-to-Learn (A2L) Project, proposed that progress and mastery in teaching problem solving and conceptual understanding (through a focus on the learning process and cognitive development) involves five steps: 1) searching for the prior knowledge and launching of new ideas, 2) working on and connecting the concepts, 3) using concepts to reason about situations in the physical world, 4) organizing the knowledge, and 5) developing problem solving strategies. The focus of their study was on facilitating the use of formative assessment and using technology to help teachers assess students’ cognitive development. However, the current study is only concerned with describing teacher
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thinking and beliefs about teaching problem solving more specifically in the topic of linear motion, in which the above five steps can be considered.

In a study that focused on the area of motion, Carrejo (2004) investigated the professional development of secondary in-service teachers, including 23 physics teachers, who had participated in an intensive kinematics unit as part of a professional program that was designed to address the important concepts of motion, including position, direction, velocity and acceleration. The study investigated teacher construction of a mathematical model of motion for a physics course. During this unit teachers were asked to predict the position of an object at any given time, when doing different motion experiments in a laboratory. Results confirmed that there was an improvement in the post-test average scores, indicating “teachers’ recall of a memorized equation format” or “teachers’ reliance on a memorized procedure” (p. 64). Although teachers were better able to respond to the quantitative-type questions on the post-test, “clear indications of where teacher strengths and weaknesses lie with regard to conceptual understanding of motion equations was not apparent” (p. 63). Carrejo’s course evaluation study revealed little about the CK and PCK of the teacher in the area of motion and did not focus on teachers’ beliefs about problem solving in motion. However, the current study is concerned with teacher CK and PCK through exploring teacher thinking about problem solving and teacher feedback on student difficulties in solving linear motion tasks.

Gerace and Beatty (2005) found that in traditional physics instruction, teachers’ application of problem solving seems to emphasize a specific goal (such as calculating a physical quantity), to use a single principle or procedure, to relate to worked examples, and to ignore the real-world situations in order to determine the answer. This is primarily based on the superficial features of situations, and is called means-ends analysis and equation manipulation. As a result, these authors (2005) concluded:

What students don’t do, but should, is: analyze situations in terms of concepts; interpret mathematical formalism; employ multiple representations; seek and weigh alternative solutions; formulate a strategy before solving; compare and contrast with more familiar situations; and monitor and reflect upon their own problem solving.

(p. 6)
Chapter 2: Literature Review

The current study was concerned with teacher beliefs about how the teaching and learning of problem solving in the specific area of linear motion should proceed. This in turn informs teacher feedback on students’ written solutions in this area, which is the focus of this study.

2.4.3 Teachers’ content knowledge and feedback on student difficulties

There is much research on teachers’ content knowledge which has been given a range of meanings and considered from different points of view. For example, Schwab (1964) defined two types of subject matter knowledge: the substantive and syntactic. However, Grossman, Wilson and Shulman (1989) sought a more comprehensive catalogue of expert teacher knowledge in various subject areas and added two other categories of subject matter knowledge, that in the context of the current study are: (1) content knowledge which includes understanding of the motion in real-life, motion concepts, and the process of motion problem solving, and (2) the common sense understanding of students or teachers about the motion discipline.

Grossman, Wilson and Shulman (1989) and Loughran et al. (2001) suggest that teacher CK is an important component of teachers PCK. Gess-Newsome (1999) noted that “teachers with strong conceptual knowledge have more detailed knowledge of the topic, more connections and relationships to other topics, and can easily draw upon this knowledge in teaching and problem solving situation” (p. 63).

The analysis in the current research of physics teacher responses and intentions revealed various aspects of teachers’ knowledge. This knowledge was assumed to underpin the teacher feedback. My study also focuses on the teachers’ beliefs about students’ knowledge and skilled knowledge of teaching linear motion through problem solving.

As explained in 2.3.1, Tuminaro’s (2004) study suggested that there are differences and similarities in the use of the two epistemic games mapping mathematics to meaning and recursive plug-and-chug, when played by an expert as opposed to a novice problem solver in a particular physics problem. The structural components of these two epistemic games are similar, while the mathematical resources (ontological components) are different. The experts often play the mapping mathematics to meaning game which helps them make sense of the symbolic equations and use the equations to arrange and manage their conceptual knowledge. This approach provides an important skill in order to foster a meaningful problem solving strategy (explained at the end of
2.3.2). In the context of the current study it was assumed that teachers, who have a rich content knowledge in the area of motion, could enable meaningful problem solving. Tuminaro (2004) proposed that the novice plays a recursive plug-and-chug game, which does not activate the conceptual and epistemological resources that would help them make sense of mathematical symbolism in a physics equation.

With respect to the student use of equations, Tuminaro (2004) proposed that many students use equations without making sense of the mathematical symbolism involved in these equations. While some of the moves are similar in mapping mathematics to meaning and recursive plug-and-chug (they both involve the identification of a target concept and an equation, and mathematical manipulations), the cognitive and epistemological resources that are active in the two games are different. In the current study, having knowledge about the content of problem solving may lead teachers in their interpretations of the problem solving processes used by students. Then, teachers may interpret students’ novice behavior for expert-like behavior, which clearly has negative consequences in student understanding and learning, for instance, through encouraging rote problem solving behavior by recursive plug-and-chug, and inhibiting students’ meta-cognition in monitoring and evaluating their own problem solving strategies.

In a study on fifteen graduate pre-service teachers attending a physics course, Marshall and Carrejo (2008) reported that although some of their study participants were familiar with standard motion concepts (velocity, position, and acceleration), they could not appropriately use these concepts to characterize motion. These beginning teachers described accelerated motion in terms of changes in average velocity, in contrast to the correct physical concept of such motion (in terms of changes in instantaneous velocity). That is, these pre-service teachers’ understanding of basic kinematics concepts was weak.

Dagher and Cossman (1992) reported that one-fourth of teacher participants in their study used inaccurate explanations of science topics in their responses to their students’ difficulties, while Sanders, Borko and Lockard (1993) found that even though, in some instances, science teachers were aware of students’ difficulties with a momentum topic, their explanation confused themselves and the students. They concluded that this observation may be explained by the fact that for those teachers the topic of momentum was outside their expertise. In my study, through analysing teachers’ strategies in solving the standard and non-standard motion tasks and their comments on student
responses in solving such tasks, teachers’ content knowledge levels have been explored. Knowledge of physical and mathematical procedures of motion tasks and their coordination are encompassed in teacher content and skilled knowledge.

The assumption that experienced teachers can be considered expert problem solvers and have a rich content knowledge of motion in responding to student difficulties will be examined in the current study. diSessa, Hammer, Sherin, and Kalpakowski, (1991) argue that there are individual differences among experts in problem solving, for example among teacher experts, while some work from hypothesis to proof, others switch from generalisation to specific case perspective and vice versa. They suggest that expert teachers may give different responses to a similar situation of student difficulty, which reflect variations in the teachers’ PCK in the area of motion.

The studies of teachers’ skilled knowledge reviewed above underpin the exploration in the current study of physics teachers’ responses to high school student solutions to linear motion problems. The investigation of teachers’ written responses to written hypothetical student solutions demonstrates a method for exploring the nature of teachers’ skilled knowledge.

Summary

Teachers’ dispositional knowledge about student thinking about motion, and teacher interpretations of student uses of mathematics in devising solutions to motion tasks are important. If a teacher does not have the propositional knowledge of the underlying concepts of the mathematical and physical thinking in the context of linear motion, then they are likely to play the recursive plug-and-chug game with their students and not assist students to construct a deeper understanding. The current study, through the case studies of the intent of 11 physics teachers as revealed in their feedback to surrogate students on their use of the kinematics equations in their problem solutions, attempts to provide a fine grained account of teachers’ pedagogical knowledge.

In the next chapter, the theoretical framework for this study will be elaborated.
Chapter 3: Theoretical Framework

3.1 Seeking an account of ‘good’ physics teaching

This thesis directly explores situated teacher beliefs and knowledge. It questions the research practices, procedures and rules used by those who study the planned behaviour of teachers assuming that they understand teachers’ personal beliefs in specific transactions. These studies often highlight knowledge-behaviour relationships because of their apparent ability to predict and explain teacher behaviour. In particular this research questions the premises of causal relations and the necessary claim that process–product research in the study of teacher behaviour deals with personally held beliefs (Shotter, 2006). Such premises would seem necessary in much of the work in science education for the purpose of enabling explanation and prediction of teacher behaviour. Just because a researchers’ explanation and prediction may appear to gain empirical support, it does not follow that their premises of teacher belief are supported. Unlike those studies that interpreted questionnaire responses to be key points in personal decisions, it is more plausible to understand these responses in the context of the action of answering the questions, in this study, in commenting or responding to a particular student solution and social context of problem solving.

The interest in the person of the physics teacher and his or her discursive acts and actions is consistent with a more person centred approach. Unlike a ‘cause and effect’ explanation of teacher behaviour this study assumes that the responses of the teachers to surrogate students’ solutions, in a familiar lesson plan format, could be explained as the actions of teachers made in compliance with what they took tacitly or explicitly to be acceptable rules of behaviour. That is, it is to do with representing the disciplinary thinking of Physicists to students, their understanding of relations between the physical entities expressed in the formula $v = u + at$ in different problem contexts, and responding to student thinking about the particular problem task in a way which facilitates the construction of personally meaningful student understandings (Harré, 2005).

It was assumed in the design of the study in a general sense that teachers and students knew what they were supposed to be doing in order to use terms they had been taught, tools (referencing the detail in the problem text itself) and other means, such as using prior knowledge acquired in various ways in class activities and life experiences,
in the everyday class task of solving a physics problem. The teachers and students were taken to be capable, again in a general sense, of monitoring their own performances and to have the capacity to step back and be aware of their self-monitoring. The teachers were understood as being able to undertake purposeful actions in the light of anticipatable responses from their students, were assumed to know what they were doing, and had the ability to choose how to behave, and to be aware of the consequences of their actions. The study defined students and teachers as persons socially, because a person cannot be treated as a person, or even call themselves a person, without at some point having another person name them as a person. The teachers and students in this research were persons, a term used in language attributed on the basis of the demonstration of skills and abilities, such as making personal decisions and being able to hold a conversation with others including the researcher.

A range of relevant literature was reviewed in the previous chapter. ‘Good’ physics teaching is associated with balancing dual attention to disciplinary thinking and student thinking in transacting conceptual change and problem solving skills.

3.1.1 Conceptual change

The literature on research into conceptual change has important implications for teaching approaches in Physics. In particular, it points to the need for physics teachers, in their discursive practice, to anticipate and respond to student thinking in important discipline specifying contexts.

For example, Duit, Niedderer, and Schecker (2007) asserted that a constructivist view of conceptual change in students learning science “places emphasis on developing new teaching and learning approaches that deliberately take students’ pre-instructional views, beliefs, and conceptions into account” (p. 606). They noted that

The particular difficulty of conceptual change in the process of learning physics appears to be that usually students’ pre-instructional conceptions about phenomena are deeply rooted in every day experiences and are therefore in stark contrast to physics conceptions. (p. 606)

As a consequence, conceptual change teaching approaches generally focus on the ideas about physics phenomena that students bring to class. For example, when teaching the topic motion, Duit et al. noted that “elicitation of students’ own ideas helps (both
them and the teacher) to contrast their intuitive views with the scientific notion of force” (2007, p. 617).

Similarly, Clement (1983) argued that teachers could use students’ existing ideas as starting points for teaching sequences directed at constructing students’ formal understandings of Newtonian concepts. Teachers themselves were assumed to have a rich content knowledge which was seen as necessary for developing and using teaching approaches that promote student understanding, a point that will be returned to later. However, Clement (1983) and Duit et al. (2007) did not elaborate on how teachers integrate the need to represent the formal physics concepts and respond to student thinking about the concepts. This is the dual focus of the current study.

The development of students’ conceptual understanding in physics presents particular challenges to physics teachers, given the emphasis on mathematical modelling and problem solving in most physics curricula. As Duit and his colleagues (2007) note:

Radical idealization and decontextualization, the reduction to pure phenomena accompanied by particular mathematical modelling, seems to be a major hurdle for students to understand physics concepts and principles. (p. 606)

Consequently, researchers now advocate that teachers should focus on the development of students’ qualitative understanding of physics concepts and principles before introducing mathematical representations of these ideas (Mulhall & Gunstone 2008; Nashon, 2007). However, this literature did not explore teachers’ dispositional knowledge or beliefs and knowledge in providing feedback, with respect to the use of formulae in the context of problem solving, particularly in the linear motion topic.

This research explores teachers’ responses and feedback to students’ attempts to solve standard and non-standard motion tasks. Some research (e.g. Berg & Brouwer, 1991; Gerace & Beatty, 2005; Magnusson et al. 1999) has suggested that teachers usually experienced considerable challenges in constructing effective responses to student learning difficulties with physics concepts. Sanders, Borko, and Lockard (1993) also suggested that where a teacher lacked sufficient content knowledge on a specific topic they lacked the teaching expertise to respond to the students’ learning difficulties. Although they concluded that teachers’ content knowledge underpinned their feedback to the students’ responses to the motion tasks, they did not examine and describe how
teachers use their content knowledge to represent and use problem solving tasks in responding to student thinking. The current study describes teachers’ intentions and dispositions in teaching and providing feedback with respect to representing their knowledge of the theory and its application to a specific motion problem and their transactions with student thoughts and views about the task.

Roth (1987) investigated how teachers’ knowledge about science and about science learners impacted on their development of teaching strategies focussed on conceptual change. In Roth’s study, a group of ‘fact acquisition’ teachers were unwilling to integrate a constructivist approach with their old models of instruction. These teachers exposed students to information or facts as defined by text book or district science curriculum....they knew less than the other teachers about their students’ thinking and misconceptions. These teachers also tended to have a less rich understanding of science and the topic being taught. Most of them were reassigned teachers with college majors other than science. Because of their lack of knowledge about their students’ ways of learning and understanding and because of weakness in their subject matter knowledge, these teachers had a difficult time making sense of conceptual change ideas and using them in effective ways. (p. 9)

The literature discussed above suggests two important influences on teachers’ strategic effectiveness in promoting students’ conceptual understanding of a topic such as motion: (a) teacher awareness and understanding of students’ learning/difficulties, and (b) the richness of a teacher’s CK in that topic. However, the literature is silent about the integration of these two influences, considered as theoretical lenses in this study.

The current study examined teacher feedback, which draws on skilled knowledge in representation and response in particular dynamic episodes.

3.1.2 Problem solving

In this section I consider research related to this important area: constructing conceptual understanding in problem solving in physics, and mathematical modelling in physics teaching. Because problem solving and conceptual change issues are often intertwined in physics teaching and learning, some of the ideas discussed earlier are revisited below.
Hobden (1998) found the use of routine problem solving exercises in teaching science, for example kinematics, was not effective in promoting conceptual understanding.

The students’ interpretations of [routine] problem tasks result in flawed understandings of their roles as learners. Consequently, they adopt strategies enabling them to attempt to solve problems without understanding through focusing on algorithms and predictable characteristics of the problems. (p. 228)

This is consistent with the claim by Duit and colleagues (2007) discussed earlier, that the kind of mathematical modelling that is typically used in standard motion tasks is often unhelpful in promoting conceptual understanding in physics learners. However, exploration of teacher knowledge and beliefs about the significance and skilful use of the formulae in solving linear motion tasks is a gap in literature.

It was argued by McDermott (1993), Conn (1995), and Redish and Steinberg (1999) that a good problem solver should have a high level understanding of physics concepts (what the physics is about) and a well-developed knowledge structure (how the physics concepts fit together). Clearly these requirements apply to physics teachers as well. In addition, however, Duit et al. (2007) claim that with respect to teaching a topic such as motion, teachers need to be able to transform the content into a special knowledge for teaching that takes into account of students’ learning needs and perspectives and also the aims of teaching motion. This literature does not explore the variations in teachers’ thinking or beliefs and knowledge across the complexity of students’ use of formulae in problem solving strategies in the topic of linear motion.

Hobden (1998) concluded that problem solving exercises are regarded by students and teachers as “ordinary, uninteresting and predictable” and instead should be presented as “creative, interesting, and useful” (p. 228). Hobden also suggested that teachers should focus on “the development of qualitative understanding”, instead of engaging predominantly with the status of “quantitative methods of representation and algebraic methods of solution” (p. 229). More recently, Gaigher, Rogan, and Braun (2006, 2007) have shown that a structured problem solving strategy that involved qualitative analysis successfully developed students’ ability to solve problems with conceptual understanding rather than using an algorithmic approach. Importantly, the approach fosters student thinking and engagement with physics ideas and is quite
different to common “teacher-dominated approaches” which attend primarily to
mathematical transformations. (Gaigher et al., 2007, p. 1108). Some of the literature
(e.g. Clement, 1983, 1994; Sherin, 2001) proposed the importance of understanding of
the use of the physics formulae through using ‘schema’ based on principles of physics,
where the structure of a schema corresponds to the steps involved in solving a problem.
While the current study does not analyse student problem solving skills per se, it
explores how the teachers would plan to introduce problem solving tactics to students
and asks teachers to interpret and write feedback on, students’ written solutions. In the
current study problem solving is taken to specifically mean the development of physics
concepts including understanding the mathematical modeling involved. Each teacher
was asked in interview, at certain points, to simulate conversations they would have
with a student about their particular written solutions to particular tasks. The teachers
are asked to discuss their teaching approach to enacting a meaningful problem solving
教学策略。教师应根据需要，例如，指示如何在对话现实中使用图表或方程
create a ‘hinge’ between
disciplinary
discourse in physics.

Different features of ‘good’ physics teaching were presented in the literature and
arose from my experience of teaching physics and professional references (Halliday,
Resnick & Walker, 1994) as to tactics that they could suggest to students to assist them
to move on in solving a motion problem in a way that is likely to be meaningful to the
students. These elements of ‘good’ teaching comprised a form of clue structure I
commenced my interviews with. I surmised that in my discussions with the eleven
physics teachers some form of these elements and tactics (see Figure 3.1 below), along
with others, would be elaborated in their interpretations and responses to the student
solutions and also in their accounts of their approach to teaching meaningful problem
solving in linear motion to senior high school students.
The researcher’s clue structure for interpretation of teacher accounts of their teaching and the tactics for students to use in meaningful problem solving of motion tasks

- Careful reading of the problem and explaining the physical entities including their vector qualities in order to understand the situation of the problem

transferring meaning to the mathematics involved in problem solving

transferring the mathematics (graphs and equation) to the meaning of physics concepts through the following tactics

- using graphs:

  Tactic (a): sketching an appropriate graph

  Tactic (b): interpreting the graph in the real life or problem context

- using equations:

  Tactic (a): defining the terms and their units of measurement: e.g. using words/sentences instead of algebraic symbols in a possible equation.

  Tactic (b): using and discussing possible ways of interpreting a possible equation.

- using algebra, words, numbers in the process of problem solving:

  Tactic (a): using words including units of measurement in writing kinematics formulae prior to the final step of problem solving.

  Tactic (b): substituting numbers only in the final step of problem solving to avoid numerical rounding errors

  evaluating the solution for common sense magnitude and units.

*Figure 3.1:* Tentative clue structure for interpreting teacher accounts of teaching meaningful problem solving in the current study.

Clearly the features or tactics of a framework for meaningful problem solving were not assumed to be known nor were they thought to be equally important to all teachers who would integrate them in different ways in different linear motion problems. Likewise it was not surmised that a particularly powerful strategic sequence of instruction in problem solving would be discovered.
To summarise, in this study ‘Problem solving’ is a phrase that is popularly used to describe both a teaching context and an important intellectual outcome in physics and mathematics instruction, considered as theoretical lens of this study. With respect to the aim of this study, an ideal teaching practice was pictured as an expressive and not simply practical process of iterative interpretation and feedback to a student that focused on both their expressed thoughts/views, and the status of their formal understanding of physics concepts, appropriate to their stage of conceptual development and the instructional phase they were engaged in. I aimed to explain the nature of the teachers’ feedback drawing attention to their construction of student thinking and their representation of the formal physics concepts. In this regard I explored teachers’ predispositions and skilled knowledge in attending to both student views and the topic of motion.

3.1.3 Teacher propositional subject matter knowledge

The literature suggests that teachers need a rich content knowledge to be able to develop and use effective approaches for promoting conceptual change and meaningful problem solving in specific topics such as linear motion.

Furthermore, Gess-Newsome (1999) referred to five overlapping types of teacher knowledge in the literature, including “conceptual knowledge, content-specific orientations to teaching, and contextual influences on curricular implementation”, and concluded that the length of experience in teaching physics was not a guarantee for either an enriched teacher CK or PCK:

[T]eachers having low levels of subject matter knowledge often teach for factual knowledge, involve students in lesson primarily through low level questions, are bound to content and course structures found in textbooks, have difficulty identifying student misconceptions, and decrease student opportunities to freely explore the content either through manipulative or active discussion. (p. 82)

The above quote, which is consistent with Roth’s (1987) research mentioned earlier, suggests that the teachers, who have low levels of content knowledge, rely heavily on practical instructional sequences found in the textbook. This may be a reason why research by Arzi and White (2008) showed teachers’ subject matter knowledge does not necessarily develop over time or with experience of teaching. Because this study was concerned with exploring and understanding teachers’ expressed feedback on student
responses to motion tasks, the research investigated possible links between teachers’ content knowledge and their feedback.

3.1.4 Teachers’ skilled knowledge and teaching motion

The literature on conceptual change and problem solving imply that teachers with good skills for teaching motion focus on student thinking and on fostering conceptual understanding and the development of meaningful problem solving behaviours.

An understanding of the following two key components of teachers’ skilled knowledge, guiding their intentions or agency, are taken to be particularly relevant to the reflexive teaching of motion, and to this study:

1. knowledge about the learning and the teaching of motion and problem solving that teachers enjoin to promote students’ conceptual understanding and ability to solve linear motion tasks. This can be accessed in this study from the teachers’ accounts of the characteristics of good physics teaching or from their knowledge and beliefs about general and specific aspects of learning and teaching linear motion, particularly in and through problem solving. For the purposes of this study I did not seek to distinguish between beliefs and knowledge (Kagan, 1990; Mason, 2004), in investigating teachers’ intent, and have often used the terms interchangeably.

2. knowledge about student understanding in motion and solving linear motion tasks, and teachers’ awareness of students’ common understandings and areas of difficulty in the topic. These notions in the context of the current study I sought through exploring teacher interpretations of written student responses.

As shown in 3.1.1 and 3.1.2, having a rich content knowledge is considered to support the above components of teachers’ skilled knowledge and the research design took into account the exploration of possible relationships between these components of skilled knowledge, teacher content knowledge, and teacher feedback.
Summary and General assumptions:

This study was concerned with the conventional dynamics of planned physics teaching in the common classroom transaction of problem solving. The approach allowed the researcher to see the subject as a choosing subject, located in a surrogate transaction according to a narrative form with which they are familiar and bringing to that narrative and commentary their own subjective lived history through which they present an account of physics teaching which they have learnt, metaphors of teaching, tools in the form of physics ideas, students as characters, and plot line as in curriculum coverage and examination success.

A view of language as only having a representational function is implicitly present in academic research in psychology, even within a social constructionist orientation which sees the teacher’s task as that of understanding talk ‘about’ mental states from which students’ acts spring. Drawing attention to responsive or interpretive functions of language is not to argue that the representational view of language is wrong but just to draw attention to the fact that our ‘picturing’ a state of affairs is just one of several different kinds of use of what are called ‘symbols’, ‘words’, ‘sentences’ in the problem task set for the student and the transactions that follow (Harré, 2005). Cognitive misconception research may be driven by a single particular ‘grammatical picture’ of, not only what it is for a student to have an understanding of the physicist’s mind, but also, of what it is to have an understanding of a student’s understanding. This is the picture theory of mind, the idea that students or teachers understand events in their surroundings only indirectly, in terms of a representation made up of separate elements that can be reconfigured in a rule-governed way, ahead of time, to give a ‘prediction’ of future outcomes, in this case how to correctly answer the problem. Rather than such research being indicative of what is involved in teachers’ understandings of what is involved in students developing an understanding of what is in the teacher’s mind, such research may be more indicative of the degree to which the teachers subjected to such research tend toward the same ideology of those testing them.

This current study has exploited a more complex and intricate methodology appropriate to the subject that assumed teachers can and must have skilled pedagogical knowledge of both representation and response which they express in similar contexts in different extraordinary ways. The investigation of both teacher interpretations of, and feedback on student’s responses to linear motion tasks involved exploring teacher’s
cognition, defined by Kagan (1990) as any of teachers’ “beliefs and knowledge about teaching, students, and content; and/or awareness of problem-solving strategies endemic to classroom teaching” (p. 421). I am therefore concerned with the representations and activities that physics teachers use in teaching.

This study addressed to research questions through using three relevant lenses/assumptions about teacher interpretation and feedback to student solutions as below:

1- **Assumption about appropriate teacher interpretation of student responses to solving a motion task:**

An appropriate or specific interpretation requires a rich content knowledge, and should focus on or attend to both student thoughts and the formal motion concepts required. For example, a good interpretation of student responses should attend to evidence of the student’s strategic thinking about the use of the information provided in relation to the problem posed. This interpretation should be concerned with student need to command a personal meaning in the problem posed, rather than seeking to achieve what they think is the answer that the teacher expects and that they ought to know.

2- **Assumption about effective/specific feedback to student responses to solving motion tasks:**

Effective or specific feedback is supported by a rich content knowledge and focuses on student views and needs as well as the formal disciplinary ideas about linear motion. It enables teachers to promote student use of meaningful problem solving. For example, the contexts of the Bike task (which assumes the student commands a purely representational use of the mathematical equation $v = u + at$, see Appendix A) and the Shoved Block task (which assumes the student commands a heuristic use of this equation, see Appendix B) include some conversationally real student beliefs, which teachers could use as beginning points to explore and develop student facility in disciplinary discourse about linear motion. In this it was assumed that it is important that teachers use their rich content knowledge to teach meaningful problem solving to perspicuously represent formal concepts in their response to student thinking about the problem. In this the skilful use of the specific text of the problem task itself is strategic.
Chapter 3 : Theoretical Framework

3- Assumption about relationships between teachers’ interpretations of student responses and the feedback they give to student:

The teachers’ interpretations of student solutions focused on interacting with both student thoughts/views and the disciplinary grammar should be strategically related to their feedback and attends to the promotion of meaningful problem solving.
Chapter 4: Methodology

4.1 Introduction

The focus of this study is the examination of teacher intentions in providing feedback on student written solutions to problem solving tasks. In the previous chapter, I presented the literature for two relevant key concepts in this research, viz. conceptual change, and problem solving, which implicated in arguments that ‘good’ physics teaching pays dual attention to both the students’ prior knowledge and the formal physics concepts being developed when providing feedback on student solutions to motion tasks. As explained in the theoretical framework outlined in Chapter 3, teacher interpretation of student solutions to linear motion tasks, teacher’s propositional and dispositional knowledge about teaching and learning motion inform teacher feedback on student solutions.

The research questions addressed by this study are:

1- How do high school physics teachers interpret correct and incorrect student solutions to standard textbook and incorrect student solutions to non-standard motion tasks in physics, and on student explanations of the physics formulae?

2- How do high school physics teachers provide feedback on correct and incorrect student solutions to standard textbook and incorrect student solutions to non-standard motion tasks in physics, and on student explanations of the physics formulae?

To address the research questions, exploration of physics teacher knowledge and beliefs about teaching and learning of motion were structured into the research design, and into the analysis of the discursive behaviour of eleven physics teachers.

This chapter will discuss the methodology adopted to address the aims of the study. This is presented in three main sections. The first section (4.2) is a justification of the choice of research method. In the second section (4.3), an overview of the study is presented. The third section (4.4), details the data collection, including participants, procedures, and the instruments selected to address the research questions. In the three last sections (4.5-4.7) the different steps of the data analyses, analytical theory, and the conduct of the actual analysis will be detailed.
4.2 The study approach

In this study the thinking and discursive approach of physics teachers when teaching problem solving of linear motion tasks in the upper secondary school level were explored. Teacher thinking was defined by Kagan (1990, p. 421) in terms concerning “beliefs and knowledge about teaching, students, and content; and/or awareness of problem-solving strategies endemic to classroom teaching”. An investigation of teacher beliefs about effective teaching approaches for teaching problem solving in the physics topic of motion were part of the investigation of teacher intentions. In other words the use of problem solving as a goal and a method was chosen to explore teachers’ socially situated intentional or skilled thinking. This is consistent with social ontological approaches 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). 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 describe 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.

In order to address the research questions a qualitative research approach was considered the most appropriate. A case study approach can explore how a specific group acts in a particular situation, as well as produce understandings of the entity being studied (Burns, 2000). Moreover, Patton (2002) claimed: “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” (p.14).
This research seeks to describe teacher purposive thinking in their discursive practice (Harré, 1990) in teaching linear motion tasks. The methodology used surrogate student solutions in the current study and while this offered practical and logical advantages it also has its own limitations. A lack of resourcing limited opportunity for the researcher to access real time teacher discussions with their students. This limitation is discussed further in Chapter 7.

4.3 Overview of study

Based on the aims of this study, and in order to address the research questions, it was decided to use a case study approach for the physics teachers incorporating a problem centred questionnaire and a problem centred interview 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 Problem-Centred Questionnaire (PCQ) (see Appendix A) and a qualitative Problem-Centred Interview (PCI) (see PCI schedule in Appendix B) 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). In a PCI approach, Witzel (2000) has stated that,
The insight gained through data collection and evaluation must rather be organised as an inductive-deductive mutual relationship. The inevitable previous knowledge which must thus be disclosed serves in the data collection phase as a heuristic-analytical framework for ideas for questions during the dialogue between the interviewer and respondent. At the same time, this principle of disclosure is manifest in that through narration what the observed subjects determine to be relevant is stimulated. (p. 2)

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. More detailed information about collecting the data will be outlined in section 4.4.

4.4 Data Collection

In order to explain the procedures of the data collection process, it is important to explain the participants and instruments, including the designing and trialling of the instruments. These are detailed in section 4.4.1 and 4.4.2. The procedure of qualitative content analysis is then explained in 4.4.3.

4.4.1 Participants

Twenty secondary physics teachers from metropolitan Melbourne schools were chosen and invited to participate in the study, through an invitation letter and a plain language statement. These teachers’ experiences ranged from 3 to 35 years in teaching physics in secondary schools. Interviews were continued with the participants until I felt I had obtained from each adequate data to address the research questions. Nine teachers lost interest or could not find time to continue their involvement. 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.

4.4.2 Instruments design

As previously explained, it was decided to use a case study approach that incorporated interview based questioning and discussion, including examples of both standard and non-standard motion tasks. The process of designing the instruments included selecting several kinematics problems, and then having a selection of these problems solved by students from high schools in Melbourne, and also some first year university physics students from The University of Melbourne. The difficulties experienced by these participants in solving kinematics tasks were similar to student difficulties in using mathematics in physics, as identified previously in the literature section. In order to select the items for the questionnaire, three different kinds of solutions to the standard motion tasks were considered. These solutions included student difficulties in understanding kinematics equations and taking a meaningful approach in solving the motion tasks in the items, and student difficulties in making a link between their previous experiences and use of kinematics equations (explained in Chapter 2). These difficulties were also considered in the designing of the items and problems for the PCI. 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 questionnaire about modelling and argumentation-proof in teaching mathematics in Year 8-10 across different countries (Schwarz, Leung, Buchholtz, Kaiser, Stillman, Brown, et al., 2007, 2008). The PCQ consisted of three sections:
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In the first section, the teacher was asked to solve a standard task (see Figure 4.1, Bike task) from the 2007, Year 12 physics exam in Victoria.

Fred is riding his bike on a level road at a speed of $5.0 \text{ m s}^{-1}$. 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 4.1: 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 (shown in Appendix A). 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 $v = v_o + at$ 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 kinematics formula \( v = v_0 + at \) (shown in Appendix A). The set of three written explanations are below.

The first explanation which is coded as Mary’s explanation is shown in Figure 4.2.

It [the above equation, \( v = v_0 + at \)] means a starting bit plus a movement bit [writes “velocity = starting bit + movement bit”]. And the starting bit [circles “starting bit”] was the base which was zero speed and this one [circles “movement bit”] was the movement caused by \( g \).

*Figure 4.2: Mary’s explanation of the formula \( v = v_0 + at \).*

The second explanation which is coded as Michelle’s explanation is shown in Figure 4.3.

Well yeah it is obvious because, well velocity will equal to \( V_0 \) if it’s not being disturbed. But if it’s being acc— If there’s a \( f \)—acceleration action on it, then uh—and that’s constant, you know then velocity will be decreasing as time goes on. Or increasing, whatever works, I mean whichever it does. So, it’s like whatever it is and then plus a correction on the acceleration. So yeah it makes sense. It’s obvious, yes it is.

*Figure 4.3: Michelle’s explanation of the formula \( v = v_0 + at \).*

The third comment coded as Simon’s explanation, is shown in Figure 4.4.

What’s obvious to me is that you have the final velocity, which is obviously going to be equal to the initial velocity plus however much, however faster it gets. That’s what’s obvious to me. What’s not necessarily positively obvious is that the amount, the amount that it gets faster is the acceleration times the time.

*Figure 4.4: Simon’s explanation of the formula \( v = v_0 + at \).*

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 two tasks (shown in Appendix B): first a standard physics task extracted after Tuminaro (2004) which is called the Glider task (see Figure 4.5) thereafter, and second a non-standard task extracted after Sherin (2001) which called the Shoved Block task (see Figure 4.6) thereafter.
The mass of glider A is one-half that of glider M (i.e. \( m_M = 2m_A \)). Apply Newton's second law \( F_{\text{net}} = m\Delta v/\Delta t \) to each of the colliding gliders to compare the change in momentum \( \Delta p = m\Delta v \) of gliders A and M during the collision. Discuss both magnitude and direction. Explain.


**Figure 4.5:** Glider task.

Both tasks were already modelled by a picture. The content of the Glider task is common in physics classrooms in Victorian secondary schools.

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.


**Figure 4.6:** 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 the Glider task, which explored the teaching and personal strategies of the teacher participants. These were evoked when the teachers were presented with the challenge of teaching and using the formulae in solving the Glider task. These were followed by questions concerning the teachers’ general thinking or beliefs about their students’ difficulties in solving the Glider task.

- Questions regarding the Shoved Block task outlined in Figure 4.6, 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 4.7.
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 4.7: Mike and Karl’s discussion about solving the non-standard task.

In selecting the items to be part of the questionnaire and the interview it was important to ensure there was appropriate meshing of the research questions and the items in the PCQ and PCI. Tables 4.1 and 4.2 show the PCQ and PCI items. In order to address the first and second research questions, written student solutions to a specially developed set of physics problems were used to explore teacher thoughts or intentions embedded in their written comments. 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.
The PCQ items were linked to both research questions. It needs to be noted that items 1.2a and 2.2a linked indirectly to the second research question. This is because teacher interpretations of student difficulties may underpin the feedback that teachers provide. In a similar fashion Table 4.2 shows the PCI items linked to the research questions.

**Table 4.2**

**PCI Items**

<table>
<thead>
<tr>
<th>PCI items</th>
<th>RQ1</th>
<th>RQ2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Teachers strategy to teach the Bike task and follow up questions about such tasks</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>2- Questions about the Glider task</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>3- Questions about the Shoved Block task</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>4- General questions</td>
<td>√</td>
<td>√</td>
</tr>
</tbody>
</table>

N.B: RQ1 = First Research Question; RQ2 = Second Research Question
4.4.3 The procedure of qualitative content analysis

A synthesis of Flick (2002, 2006) and Mayring (2000) provided the procedure for qualitative content analysis in ten steps:

1. Defining of the material
2. Analysing the situation of data collection
3. Data collection sites
4. Writing about the target variables for each item
5. Refining of research questions if necessary
6. Choosing analytical techniques, which in the context of this study, summarizing content analysis was used
7. Defining analytic units, which includes coding units (smallest element of material), contextual units (the largest element of material), and analytic units (passages that are analysed one after the other)
8. Conducting actual analyses
9. Interpreting of results with respect to the research question
10. Validity.

All ‘data’ in this study, accounts of teacher knowledge and beliefs, uttered in the interviews were analysed according to the procedure of the qualitative content analysis, as explained below:

Steps 1-3: With respect to steps 1-3, all eleven teachers filled out the PCQ, and then were interviewed in their schools, except one who was interviewed at The University of Melbourne.

Steps 4-5: With respect to steps 4-5, Tables 4.3 and 4.4 show the target variables for the PCQ, and PCI items (see Appendices A and B), respectively, developed in the pilot study. The research questions were refined over the course of the 15 month interview program.
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Table 4.3
Target variables for PCQ items

<table>
<thead>
<tr>
<th>Targets of PCQ items</th>
<th>PCQ items</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.1   1.2a 1.2b 2.1 2.2a 2.2b</td>
</tr>
<tr>
<td>Teacher P.s strategy to the Bike task</td>
<td>√       -   -   -   -   -</td>
</tr>
<tr>
<td>Teacher interpretation of student solutions to the Bike task</td>
<td>-       √   -   -   √   -</td>
</tr>
<tr>
<td>Teacher feedback on student solutions to the Bike task</td>
<td>-       -   √   -   -   √</td>
</tr>
<tr>
<td>Teacher beliefs about teaching and learning the motion formula</td>
<td>√       -   -   √   -   -</td>
</tr>
<tr>
<td>Teacher interpretation of student learning difficulty to use of the formula</td>
<td>-       √   -   -   √   -</td>
</tr>
<tr>
<td>Teacher feedback on student use of the formula</td>
<td>-       -   √   -   -   √</td>
</tr>
</tbody>
</table>

N.B: P.s = Problem solving

The questionnaire included two parts: item 1.1 was used to explore teacher problem solving strategy for the Bike task and their content knowledge (CK) level. Teachers’ interpretations of and feedback on student written solutions to the Bike task were examined by using the items 1.2a and 1.2b. Teachers’ beliefs or views about teaching the formula $v = v_0 + at$ were examined in item 2.1. The items 2.2a and 2.2b were used to explore teacher interpretation of and feedback on student explanations of the formula $v = v_0 + at$.

Table 4.4 shows teacher interpretation of, and feedback on student solutions, as well as their beliefs about teaching and learning motion, are the targets of all the PCI items. The data derived from all items triangulated with examining the teacher feedback on student solution.
### Table 4.4
**Target variables for PCI items**

<table>
<thead>
<tr>
<th>Targets of PCI items</th>
<th>PCI items</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Requestioning of Bike task</td>
</tr>
<tr>
<td>Teacher P.s strategy &amp; CK</td>
<td>-</td>
</tr>
<tr>
<td>Teacher interpretation of student solutions</td>
<td>√</td>
</tr>
<tr>
<td>Teacher feedback on student solutions</td>
<td>√</td>
</tr>
<tr>
<td>Teacher beliefs of teaching and learning motion</td>
<td>√</td>
</tr>
</tbody>
</table>

N.B: P.s = Problem solving, CK = content knowledge

Step 6: With regards to step 6, which is about the analytical techniques, the summarising content analysis was used, as Flick (2006, p. 313) has suggested:

In summarizing content analysis, the material is paraphrased, which means that less relevant passages and paraphrases with the same meanings are skipped (first reduction) and similar paraphrases are bundled and summarized (second reduction). This is a combination of reducing the material by skipping statements included in a generalization in the sense of summarizing the material on a higher level of abstraction. ... You can reduce the source text by skipping those statements that overlap at the level of generalization.

**Step 7:** In this step three Analytical or diagnostic units were used in the context of this study:

- Coding units that were the smallest elements of material, for example a single word of a teacher’s sentence (see Appendix E) could be considered as the smallest unit.

- Contextual units which were considered as the largest element of material. These can be a sentence, or a paragraph or whole teacher comments to a student, and it
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was possible to give a label to a teacher by looking across all teacher comments. Appendix C may be used as a template to interpret the contextual units.

- Analytic units refer to the passages that were analysed one after the other. This includes the interpretation of the themes of teachers’ written passages, when they respond to the PCQ and PCI (see the detailed initial analysis of Mr Jackson in section 4.7). This unit was also used through applying cross references to the teacher interview excerpts, which is shown in the Appendix D.

In order to address the research questions that focused on exploring teacher intentions, it is important to explain the analytical framework used in the current study. This is explained in section 4.5. Steps 8-10 of qualitative content analysis will be explained in sections 4.5 and 4.6.

4.5 Analytical theory and analytical units

Initially the analysis involved comparing the teachers’ written comments on student solutions to identifying and interpreting any emergent patterns or regularities. This initial analysis involved a grounded theory approach (Flick, 2006 & Kagan, 1990). The detailed analysis of teacher comments (interpretations and feedback) on the student solutions helped to adjust the themes discerned at the macro level, which in turn allowed further examination of teacher thinking or the perspectives embedded in their comments. This resulted in two main groups (groups A and B), in terms of a teacher focus and the elements which were emphasised. Group A is more oriented towards a content-centred perspective, as seen in traditional teaching. Group B is more oriented towards a ‘student-centred instruction’ perspective. The implications arising from some of the literature (e.g., Redish, 1994) were taken into account to explore the extent to which teachers placed emphasis on what they themselves want students to learn, or placed emphasis on predicting student pre-instructional knowledge and/or on justifying of student interaction with and response to the content. In this study the physics teachers may have had a perspective that attended predominantly on the learning process as the key to learning and applying content, or perhaps focused on content as central to learning content application, or possibly focused on both perspectives. However, as explained in Chapters 2 and 3, neither of these perspectives was taken on their own to characterize ‘good’ teaching. Such teaching is dependent on how a teacher’s approach integrates both responsibilities in different situations. These two perspectives,
categorised as groups A and B, are explained below as descriptors of teacher orientation.

**Disciplinary Thinking and Student Thinking as descriptors of teachers’ discursive orientation**

*Category A:* The teacher comments focused on interpretation and justification of the use of physics concepts by a student and their problem solving strategy and focused less on interpreting and interacting with the student thoughts. This category comprised the teacher comments which focused on representing the ‘content’ and/or emphasised ‘teaching the content’. When the attention was on content, emphasis was placed on the correctness or incorrectness of content or student failure or success in the problem solving strategy process, and when the attention was on teaching the content, emphasis was placed on the role of the teacher and the importance of teaching physics or mathematics knowledge, rather than student needs when learning that knowledge. These aspects are shown in Table 4.5.

Table 4.5
*Coding categories A and B to ST and DT with regards to teacher interpretation and feedback*

<table>
<thead>
<tr>
<th>Categories</th>
<th>Teacher interpretation</th>
<th>Teacher feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category A</td>
<td>1- Their own (teacher’s) understanding of P.s &amp; Eq</td>
<td>1- Teacher’s need/interest in applying P.s or experiment &amp; Eq</td>
</tr>
<tr>
<td>(focus on DT)</td>
<td>2- Importance of teaching P.s strategy &amp; using Eq, rather than learning them</td>
<td>2- Importance of role of teaching P.s strategy or experiment &amp; using Eq, rather than learning them</td>
</tr>
<tr>
<td>Category B</td>
<td>1- Student thoughts of P.s &amp; Eq</td>
<td>1- Student need of applying P.s or experiment &amp; Eq</td>
</tr>
<tr>
<td>(focus on ST)</td>
<td>2- Importance of learning P.s strategy &amp; using Eq, rather than teaching them</td>
<td>2- Importance of learning P.s strategy or experiment &amp; using Eq, rather than teaching them</td>
</tr>
</tbody>
</table>

N.B: DT = Disciplinary Thinking, ST = Student Thinking, P.s = Problem solving, Eq = Equation.

As Table 4.5 shows, in the feedback on student solutions, the teacher’s emphasis is on representing what (content) or how (process) he/she (the teacher) wants the students to learn, and/or focus on teaching the content/ process rather than on student needs with respect to learning and understanding the content/process used in problem solving.
Thus, this category can best be described as Disciplinary Thinking (DT) focus (described in Appendix C).

Category B: This involves the teacher explanations including some interpretations, and expectations through interacting with student thoughts, and understandings to obtain a desired outcome. This category comprises the teacher comments which focussed on the “student” and/or “learning of the content”. When the attention was on students, emphasis was placed on the strengths and weaknesses of the student thoughts or (mis)understanding of physics or mathematics knowledge, and when the attention was placed on the learning of the content, emphasis was placed on the learning processes as key elements to learning and applying content. Consequently, in the feedback on student solutions, the teacher emphasis is more on what (content) student need to learn, and/or learning and understanding the content, through interacting with student needs rather than focussing on teaching the content. Consequently this category can best be described as the Student Thinking (ST) focus (described in Appendix C).

It seems that these perspectives are not static, but that they are dynamic, because it was not uncommon that a teacher, who had a Student Thinking focus on student X, used a Disciplinary Thinking focus on student Y. Therefore, the attention/focus that a teacher presents depends on the student solutions. It was also possible that a teacher interpretation had a focus on either of Student Thinking or the Disciplinary Thinking category, or on both Student Thinking and Disciplinary Thinking.

In the context of this study Student Thinking and Disciplinary Thinking are two basic codes, designated by Flick (2006) as “coding families”, and “these coding families are sources for defining codes and at the same time orientation for searching for new codes for a set of data” (p. 302).

The analysis of the data revealed three subcategories for Student Thinking and Disciplinary Thinking, which were supportive in fully addressing the research questions, with a focus on the use of formula and solving the tasks. These categories are explained below.

Orientation subcategories of Student Thinking and Disciplinary Thinking coding, for teacher interpretation of student solutions:

The data that emerged from the research instruments revealed that each teacher usually described and identified the content used by students, or described and interpreted the
process of problem solving or the use of the equation when a student solved the problem. In both of these situations the description and identification of student performances were the major focus. In some instances these comments were followed by a teacher diagnosis of the source of errors/success in a student solution(s). These are shown in Figure 4.8. In other words, a teacher diagnosed student errors/success, as they referred to the content used, the processes employed for the problem solving, or use of the formula (described in Appendix C).

The foregoing suggested three subcategories for “basic codes” (Flick, 2006, p. 302):

1) Description and identification of student solutions, in terms of the content used in problem solving, or the use of formula.

2) Description and identification of student solutions, in terms of the process of problem solving, or the use of formula.

3) Teacher diagnosis/anticipation of student errors.

These are shown in Figure 4.8.

![Diagram](image)

*Figure 4.8: Modeling of the teacher interpretations of student solutions.*

N.B: P.s = Problem solving, Eq = Equation.
Figure 4.8 shows that, for the purpose of this study, teacher interpretations of student solutions were taken to include teacher descriptions of student solutions and/or their diagnoses of student error/success. The analysis concentrated on references to both the content used, and the process of problem solving in teacher descriptions and diagnoses. Based on Figure 4.8, it is possible that a teacher’s interpretations might include only their description of a student’s solution, rather than including both a description of the student’s solution, and a diagnosis of the student’s error or success. Figure 4.8 shows the teacher interpretations may have been focused on either of the Student Thinking or the Disciplinary Thinking categories, or on both Student Thinking and Disciplinary Thinking.

**Orientation subcategories of Student Thinking and Disciplinary Thinking coding, for teacher feedback to a student:**

The data that emerged from teacher feedback showed that the teachers usually provided feedback about the content used in the problem solving strategy, as well as the process or strategy used for problem solving, or the use of the formula. This kind of feedback may attend to Student Thinking and/or Disciplinary Thinking. In some cases a teacher justified the importance of their feedback with an attention to the categories of either Student Thinking or Disciplinary Thinking or both (described in Appendix C). For these reasons, three subcategories for “basic codes” (Flick, 2006, p. 302) were used for teacher feedback:

1) Description of the feedback in terms of the content used in problem solving, or the use of formula.

2) Description of the feedback in terms of the process used in problem solving, or the use of formula.

3) Teacher justification of their suggested feedback, as shown in Figure 4.9.
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Figure 4.9: Modeling of the teacher feedback to student solutions.

N.B: P.s = Problem solving, Eq = Equation.

Figure 4.9 shows that in this study, teacher feedback to student solutions was modelled as consisting of description and justification of the content, the process of problem solving, and the use of the equation. The figure also shows feedback of teachers might have an attention to Student Thinking or Disciplinary Thinking or both Student Thinking and Disciplinary Thinking. Based on Figure 4.9, a teacher’s feedback might include only describing the feedback, rather than focussing on both a description, and justification, of their suggested feedback.

Extract of descriptive Analysis are provided in appendix C with respect to teacher interpretations and feedback, and the relevant subcategories (mentioned above).

Steps 8-10: Step 8 of the qualitative research analysis, the conducting of the actual analysis, is explained in the next section. This includes the Initial Analysis and Comparative Analysis.
In relation to steps 9-10, all relevant parts of each teacher’s interviews were summarised, interpreted and coded in order to explore teacher thinking with respect to the research questions. The codes from the interview excerpts were used as cross references and a triangulation tool to validate or refine my interpretations of the teacher written responses to the PCQ items. In addition, due to some of the limitations of the methodology used in this study and explained in a previous section, interpreting teacher comments and coding them as they fell into one of the Disciplinary Thinking or Student Thinking categories, might vary from interpreter to interpreter. Coding of sample teacher comments was independently conducted with three peers who were experts in mathematics and physics education at tertiary academic levels, one physics teacher who was at the time teaching in a Victorian school, and an expert in the language education field who are acknowledged at the beginning of the thesis.

Their interpretations (coding) were discussed and my coding modified as appropriate until there was consistency between us. This exercise was helpful in validating (step 10) the coding characteristics of the categories and subcategories of Disciplinary Thinking and Student Thinking.

4.6 Conducting the actual analyses

In order to conduct the actual analyses, the Initial and Comparative analyses were used to analyse the data derived from all the instruments. These analyses are detailed in sections 4.6.1 and 4.6.2.

4.6.1 Initial Analysis

The initial analysis included coding each teacher’s interpretations and feedback on student solutions to the linear motion tasks (Bike and Shoved Block Tasks) are explained below. Teacher content knowledge was also explored by examining teacher responses when solving standard and non-standard tasks.

Coding and interpreting data:

Overall each teacher was asked to provide comments about the written solutions from three hypothetical students to the Bike task, about the three student explanations of the formula \( v = v_0 + at \), and about two student written solutions to the Shoved Block task.

First, all data derived from teacher responses were coded based on the categories and subcategories explained above and shown in the extracted templates of the analysis.
(see Appendix C). An example of coding a teacher’s comments, when interpreting Rob’s solution to the Bike task is provided in Table 4.6.

### Table 4.6
Description of a component of DT with the example of a teacher’s comments, when interpreting student solutions

<table>
<thead>
<tr>
<th>Code</th>
<th>Characteristic of teacher’s response</th>
<th>Example</th>
</tr>
</thead>
</table>
| DT/C/P.s | Attention on content used in P.S.:  
The teacher explains the content they want the student to learn, rather than referring to student’s background knowledge, when interpreting student’s use of the content or problem solving strategy. | Mr Peterson said: “Rob…failed to realise the vector nature of the problem i.e \( d=v_i t+\frac{1}{2} a t^2 \)”  
Comment: The teacher wants student to learn this problem by considering its vector nature. |

N.B: DT = Disciplinary Thinking, C = Content, P.s = Problem solving

The coding explained in Table 4.6, shows that Mr Peterson had a focus on Disciplinary Thinking when he referred to the content used in the problem solving strategy, and this was coded as DT/C/P.s.

An example of coding a teacher’s comment, when interpreting the solution from Chris to the Bike task is provided in Table 4.7. Based on Table 4.7, Mr Geraldton’s comments indicate that his focus is on Student Thinking, in which the student’s thought and the learning content were commented on, rather than the teachers’ understanding of the topic and the role of teaching the content.
Table 4.7
Description of a component of ST with the examples of a teacher’s comments, when interpreting student solutions

<table>
<thead>
<tr>
<th>Code</th>
<th>Characteristic of teacher’s response</th>
<th>Example</th>
</tr>
</thead>
</table>
| ST /C/P.s     | Attention on student thoughts: The teacher explains the student’s background knowledge of the content or context, when interpreting the student’s thoughts | Mr Geraldton said: “Chris seems to have a reasonable background knowledge …”  
Comment: the above statement indicates that Mr Geraldton focuses on understanding the content, not on performing the content. |
|               | Focus on learning the content: The teacher focuses on the student’s learning, rather than teaching the content. | Mr Geraldton said: “Chris seems analytical in his approach rather than happy to simply substitute numbers into a formula…”   |

N.B: ST = Student Thinking, C = Content, P.s = Problem solving

The coding explained in Table 4.7, shows that Mr Geraldton had a focus on Student Thinking when he referred to the content used in the problem solving strategy, and this was coded as ST/C/P.s.

A detailed example of the analysis of the written and/or oral comments of a physics teacher (Mr Jackson) is discussed in section 4.7 to provide insight into the process used in the initial coding.

Second, each teacher focus was summarised, and coded in Appendix D. In order to understand each teacher’s perspective and intentions suggested by their interpretations and feedback on the solutions from the eight students, these codes were interpreted and approximately categorised across Student Thinking and Disciplinary Thinking in the tables presented throughout sections 5.4 and 5.5 in Chapter 5. In order to explore the teacher intentions for teaching linear motion tasks, their teaching approach for the Bike, Glider, and Shoved Block tasks, and their general idea about teaching-learning the motion tasks were compared and grouped based on the similarities and differences in their responses.

In the third step, each teacher’s comment, when they interpreted student solutions or provided feedback, was categorised in relation to the three student explanations of the
formula and the five student solutions to standard and non-standard linear motion tasks. This step also involved analysing the beliefs of each teacher about teaching and learning motion, through the evidence they provided when presented with the challenge of how they would teach, and their personal use of the formulae in solving two standard textbook and one non-standard linear motion tasks. General teacher beliefs, about student difficulties across the standard and non standard motion tasks, and their beliefs about being a good teacher and modelling in physics, were also analysed.

**Categorizing teacher CK levels**

To elaborate on teacher content knowledge, personal strategies of the teachers when solving the standard task for the Bike and Glider tasks, as well as the non-standard (Shoved Block) task, were analysed. Teacher conceptual understandings and competencies in solving the motion tasks were explored, and then their content knowledge was categorized into three levels: high, average, and low, which are shown in Table 4.8.

<table>
<thead>
<tr>
<th>Teachers’ competency in motion with constant acceleration</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Able to solve three motion tasks correctly.</td>
</tr>
<tr>
<td>Average</td>
<td>Generally made a start and solved the “Bike” and “Glider” tasks, but were uncertain in providing the correct solutions to the “Shoved Block” task.</td>
</tr>
<tr>
<td>Low</td>
<td>Able to solve the Bike task, but experienced difficulty making a start or solving the “Glider” and/or the “Shoved Block” tasks.</td>
</tr>
</tbody>
</table>

For example, Mr Jackson was categorised as being at a “Low level” of competency for the motion topic, as he had difficulty in recognising the unknown and the appropriate formula to solve the Shoved Block task, correctly. While he was able to explain and discuss the physical reasoning involved in the Glider task, he was reluctant to solve the task by using the algorithm.
4.6.2 **Comparative Analysis**

With respect to teacher interpretations of, and feedback on student solutions, the comparative analysis explored patterns or relationships between teachers’ foci across aspects of the student solutions and the motion tasks. These are explained in three steps:

The first step in the Comparative Analysis entailed looking for patterns of each teacher interpretations and feedback (DT or ST) across the incorrect solution from Rob and the correct solution from Chris (see Chapter 5, sections 5.4.1 and 5.5.1). This was done for teacher interpretations and teacher feedback on each student’s explanation of the formula (see Chapter 5, sections 5.4.3 and 5.5.3).

The second step in the Comparative Analysis involved looking for the patterns in each teacher’s foci across type of task (the standard and non-standard), when they interpreted or provided feedback to student. This is outlined in Chapter 5, sections 5.4.2, and 5.5.2.

The third step in the Comparative Analysis involved searching for, and then examining any patterns of all eleven teachers’ interpretations and feedback across each student solutions, and each motion task (see Chapter 5, sections 5.4.1 and 5.5.1). This was done for teacher interpretations and teacher feedback on each student’s explanation of the formula (see Chapter 5, sections 5.4.3 and 5.5.3).

As explained in Chapter 3, this study was looking to explore the three components of teacher pedagogical content knowledge which inform teacher feedback. These components are teacher content knowledge in the area of motion, teacher beliefs about teaching and learning motion, and teacher interpretation of student written solutions. The Comparative Analysis also entailed looking for patterns or relationships between the above components of teacher PCK and the feedback each teacher provided on student solutions. Some examples of these relationships are outlined in Chapter 6, sections 6.3 - 6.6.

A detailed example of the analysis of Mr Jackson’s written and/or oral comments is discussed in section 4.7 to provide insight into the process used in the initial coding.

4.7 **A detailed example of the initial analysis**

Teachers’ foci can be identified in the text derived from both written comments and the interview excerpts. As explained in section 4.4.3, step 7, these texts can be a word, a
phrase, a sentence, or a paragraph or whole teacher comments to a student, and it was possible to give a label to a teacher by looking across all teacher comments. In this section the word, phrase, sentence, or paragraph which shows the teachers attentions to either of Student Thinking or Disciplinary Thinking are underlined in the written and verbal texts.

**The Bike Task**

An in-depth discussion of Mr Jackson’s responses to each student solution is provided to clarify how the initial analysis was conducted. The foci of Mr Jackson’s attention were identified in both his written comments and the interview excerpts. Table 2 of Appendix D shows that Mr Jackson gave dual attention to Student Thinking and Disciplinary Thinking when interpreting the three students’ solutions to the Bike task. Mr Jackson’s written comments in the questionnaire regarding the three students’ (Rob, Chris, Sue) solutions and, in some instances, his oral comments in the interview about these students, reveal Mr Jackson focus. Some examples of coding for Mr Jackson’s comments are explained below.

Overall, Mr Jackson focused on both Student Thinking and Disciplinary Thinking, when interpreting Rob’s solution. Mr Jackson wrote, when interpreting Rob’s solution:

*Rob has failed to separate the two independent motions, vertical and horizontal.*

The above comment indicates a focus on Disciplinary Thinking, as Mr Jackson refers to the process of problem solving, which was coded as DT/P/P.s (see Table 2 in Appendix D). Moreover, he diagnosed a source of error in Rob’s performance with a focus on Disciplinary Thinking (code: DT/D/P.s). Mr Jackson also wrote:

*The use of the equation $v^2 - v_0^2 = 2ax$ is actually quite tricky to use correctly especially in non linear situations.*

This comment also indicates a focus on Disciplinary Thinking, as Mr Jackson refers to the process of the use of the formula (code: DT/P/Eq). However, there is some evidence in the interview that indicates a focus on both Disciplinary Thinking and Student Thinking. The following excerpt is an example:

*He’s combined both. He’s put initial velocities and gravity, so he’s got a horizontal velocity and he’s got a vertical
acceleration - all of them on the equation so that obviously is a conceptual problem. He’s missed the point. He seems to have a reasonable understanding of physics but he doesn’t have an understanding of this type of problem.

These comments show Mr Jackson’s diagnosis of the source of error in both Rob’s solution and his thinking, which in this instance indicates a focus on both Disciplinary Thinking and Student Thinking categories (codes: ST & DT /D/P.s).

Overall, Mr Jackson’s interpretations of Chris’s solutions had dual attention to both Student Thinking and Disciplinary Thinking. Some examples of his written comments are below:

Chris has done well recognizing the separation of components. Chris seems to be asking all the right questions at the start and then organizing the information in a useful form. The use of $g = 10$ was fine though sig figs [i.e. significant figures] have been ignored.

The above comments indicate attention to Disciplinary Thinking, as Mr Jackson discussed the content used in, and the process of Chris’s solution (codes: DT/C/P.s &DT/P/P.s).

He also wrote:

there is a degree of waffling in the spoken response indicating a lack of familiarity with these types of questions. This may in some way be a response to being asked direct questions about his/her thinking processes. We often do things where the subconscious is control and we cannot explain exactly how we got there but from practice it simply happens. So it could either over familiarity or the direct opposite lack of experience/confidence.

The comments indicate an attention to Student Thinking, as diagnosing the source of the error in Chris’s solution. This was coded as ST/D/P.s. In addition, he diagnosed the source of correctness of Chris’s performance with attention to Disciplinary Thinking
The following extract from Mr Jackson’s interview indicates Mr Jackson’s interpretations of Chris’s solution.

...The middle one [Chris] was a very mathematical one but obviously had practised the things and knew more about that type - and has written down these which are the initial conditions - this is the equation I want.

These comments also confirm Mr Jackson’s diagnosis of the source of the error in Chris’s solution with a focus on Disciplinary Thinking (code: DT/D/P.s).

Mr Jackson overall interpretation of Sue’s solution attended to both Disciplinary Thinking and Student Thinking. Some examples of his written comments are:

Sue gets there in the end but does not engender confidence, i.e., the use of m/s^1 for acceleration. She does recognize the need for the separation of the components quite quickly. Rounds off but not quite correctly to 3 sig figs. (0.992!)

These written comments from Mr Jackson indicate attention to Disciplinary Thinking, as he refers to the content used in, and the process of, Sue’s problem solving strategy (codes: DT/C/P.s & DT/P/P.s). However, there is some evidence in his interview indicating that Mr Jackson comments also attended to both Student Thinking and Disciplinary Thinking, when interpreting Sue’s solution. This is shown below.

She’s [Sue] obviously gone off and done a whole stack of things which are wrong because she hadn’t tried to visualize the problem first and selected out what she... So it appears that she’s gone to the mathematics and tried to plug it into equations without actually thinking about what’s actually happening and visualizing the situation and saying OK – and then she came to me - oh that didn’t seem logical, well no the approach was just to try? Trialing and plug and chug...

This explanation from Mr Jackson indicates dual attention to Disciplinary Thinking and Student Thinking, when diagnosing the source of the error in Sue’s solution (code: ST&DT /D/P.s). He also wrote:
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The crossed out section indicates lack of familiarity with the question type and perhaps an over eagerness to get started without really thinking through the process.

This comment also confirms a focus on Student Thinking (code: ST/D/P.s), when Mr Jackson was diagnosing the source of the error in Sue’s thoughts.

General Summary

Overall, Mr Jackson attended to both Student Thinking and Disciplinary Thinking when interpreting three students’ written solutions. Mr Jackson made some comments that indicated a focus on Student Thinking or Disciplinary Thinking when diagnosing the source of the three students’ errors/success. Mr Jackson’s comments were focused on a problem solving strategy rather than focusing on the use of formula in the Bike task. The summary of Mr Jackson’s interpretations of the three students’ (Rob, Chris, and Sue) solutions (see Table 2 in Appendix D) is below:

Mr Jackson attended generally to both Student Thinking and Disciplinary Thinking, when interpreting Rob’s solution when referring to both the content used in, and the process of, Rob’s problem solving strategy. Mr Jackson focused on both Disciplinary Thinking and Student Thinking, when diagnosing the sources of errors/success of Rob’s solution.

Overall, Mr Jackson’s interpretation of Chris’s solution indicates attention to both Disciplinary Thinking and Student Thinking. Mr Jackson focused on both Disciplinary Thinking and Student Thinking, when referring to both the content used in, and the process of, Chris’s problem solving strategy. He also made comments on diagnosing the source of errors/success of Chris’s solution with dual attention to both Disciplinary Thinking and Student Thinking.

Mr Jackson interpretation of Sue’s solution attended to both Disciplinary Thinking and Student Thinking when referring to both the content used in, and the process of Sue’s problem solving strategy. He also attended to both Disciplinary Thinking and Student Thinking, when diagnosing the sources of errors/success of Sue’s solution.

The formula \( v = v_0 + at \)

Table 2 in Appendix D shows that Mr Jackson attended to both Student Thinking and Disciplinary Thinking when interpreting the three students’ explanations/use of the
formula: \( v = v_0 + at \). Some examples of Mr Jackson’s written comments in response to the three students’ explanations/interpretations of the formula: \( v = v_0 + at \), in the questionnaire, and, in some instances, his oral comments in the interview about these students’ explanations, are outlined below.

Mr Jackson attended generally to both Disciplinary Thinking and Student Thinking when interpreting Mary’s explanations/interpretations of formula: \( v = v_0 + at \). Mr Jackson wrote:

\[
\text{Mary seems to have got it just about right conceptually and now needs to develop confidence by the experience of doing more problems.}
\]

\[
The \text{difference between vectors and scalars needs work.}
\]

The above comments indicate a dual attention to Disciplinary Thinking and Student Thinking when Mr Jackson diagnosed the source of the error in Mary’s interpretation/use of the equation (code: ST&DT/D/Eq).

The following explanation from Mr Jackson refers to his written interpretation of Michelle’s use of the formula:

\[
\text{Michelle seems to have some idea about Newton’s laws and the causes of the changes on velocity.}
\]

\[
\text{She appears to grasp the two parts of the equation well also.}
\]

\[
\text{Some initial confusion as to increasing or decreasing velocity under free fall.}
\]

Mr Jackson’s first comment indicates a dual attention to Disciplinary Thinking and Student Thinking, as he refers to the content (background knowledge) used in the equation (code: ST&DT/C/Eq). He also had a dual attention to Disciplinary Thinking and Student Thinking, when discussing the process of the use of the equation (code: ST&DT/P/Eq).

The following extract from Mr Jackson’s written comment indicates his interpretation of Simon’s use/explanations of the formula:

\[
\text{Simon appears to have a good grasp of the equation and that it is basically two parts – a constant and a changing.}
\]
He then understands the changing nature of the velocity due to the acceleration.

The above comments indicate the content used in, and the process of, the use of the equation with a dual attention to Student Thinking and Disciplinary Thinking (code: ST&DT/C/Eq and ST&DT/P/Eq). Furthermore, Mr Jackson diagnosed the source of Simon’s difficulties in understanding the equation with dual attention to Disciplinary Thinking and Student Thinking (code: ST&DT/D/Eq).

**General Summary**

Overall, Mr Jackson attended to both Student Thinking and Disciplinary Thinking when interpreting the three students’ (Mary, Michelle, and Simon) explanations/use of the formula: \( v = v_0 + at \).

Mr Jackson attended to both Student Thinking and Disciplinary Thinking when interpreting Mary’s explanations/interpretation of the formula: \( v = v_0 + at \). He particularly focused on both Disciplinary Thinking and Student Thinking, when diagnosing Mary’s use of the formula.

Mr Jackson attended generally to both Disciplinary Thinking and Student Thinking when interpreting Michelle’s written explanations. Particularly, he focused on both Disciplinary Thinking and Student Thinking, when diagnosing Michelle’s performance.

Mr Jackson attended to both Disciplinary Thinking and Student Thinking, when he interpreted Simon’s written explanation of the formula. He attended to both Disciplinary Thinking and Student Thinking, when diagnosing the source of error/success of Simon’s written solution.

**The Shoved Block**

Mr Jackson was not able to solve the “Shoved Block” task correctly, and made some comments indicating a focus on Student Thinking. These comments mainly referred to the content used in, and the process of Karl’s problem solving strategy (ST/C/P.s and ST/P/P.s).

**Mr Jackson’s feedback on eight students’ solutions**

Overall, each teacher was requested to provide feedback on three hypothetical students’ solutions to the Bike task, and three students’ explanations of the formulae \( v = v_0 + at \). Each teacher’s comments are analysed in terms of their suggested/proposed feedback on
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the three students’ (Rob, Chris, and Sue) solutions of the Bike task, and the three students’ (Mary, Michelle, and Simon) explanations of the formula: \( v = v_0 + at \), and the two students’ (Karl and Mike) solutions to the Shoved Block task, across Disciplinary Thinking and Student Thinking. Teachers’ foci can be identified in the text derived from both written comments and the interview excerpts. As explained in section 4.4.3, step 7, these texts can be a word, a phrase, a sentence, or a paragraph or whole teacher comments to a student, and it was possible to give a label to a teacher by looking across all teacher comments. In this section the word, phrase, sentence, or paragraph which shows the teachers attentions to either of Student Thinking and Disciplinary Thinking are underlined in the written and verbal texts.

Some examples of coding in the initial analysis of Mr Jackson feedback to eight students are below.

**Bike Task**

Overall, Table 2 in Appendix D shows that Mr Jackson focused on both Disciplinary Thinking and Student Thinking, when providing feedback on three students’ solutions to Bike task. Mr Jackson’s foci can be identified in both written comments and the interview excerpts. Some examples of Mr Jackson’s written and oral comments in response to the three students (Rob, Chris, and Sue) in the questionnaire and interview are outlined below.

Table 2 in Appendix D shows Mr Jackson overall had a dual attention to Disciplinary Thinking and Student Thinking, when providing feedback on Rob’s solutions.

Some examples of Mr Jackson’s suggested feedbacks are:

- Rob needs to recognize the independent components in this situation.
- Practical work with balls dropping and being projected would help this aspect.
- The use of videos/DVDs or applets to help develop the concepts of the independent motion is required.

These comments or feedback indicate an attention to Disciplinary Thinking, as Mr Jackson referred to the content used in the problem solving strategy (DT/P/P.s). Moreover, the above explanations indicate a focus on Disciplinary Thinking, when he
justified his feedback (DT/J/P.s). Another piece of written feedback by Mr Jackson that indicates, again, attention to Disciplinary Thinking, is below:

\[
\text{Plain old hard work and repetition through multiple examples/problems is paramount.}
\]

However, Mr Jackson did not provide any justification of the feedback which he provided. The following, of his written comments are examples that indicate his attention to both Disciplinary Thinking and Student Thinking:

\[
\text{He has some understanding and this needs to be built on.}
\]
\[
\text{He seems to visualize the motion, but fairly well and that imagination/visualization is very important with these and many other problems.}
\]

This comment that points to building “understanding” indicates a focus on Student Thinking, as Mr Jackson referred to the content used in the problem solving strategy (ST/C/P.s). This was followed by his justifications of his idea of feedback which indicates a focus on both Disciplinary Thinking and Student Thinking (ST&DT/J/P.s).

Table 2 in Appendix D shows Mr Jackson’s overall feedback on Chris’s solution had a dual attention to Disciplinary Thinking and Student Thinking. Some examples of his written comments are:

\[
\text{He has some understanding and this needs to be built on.}
\]
\[
\text{He seems to visualize the motion but fairly well and that imagination/visualization is very important with these and many other problems.}
\]

Similar to the previous comment, for Mr Jackson’s feedback on Rob’s solution, the first part of the above comments also referred to “understanding” which indicates a focus on Student Thinking, as Mr Jackson discussed the content used in the problem solving strategy (ST/C/P.s). Moreover, Mr Jackson’s comments are followed by a justification about his feedback in which he discussed “visualization”. This indicates a focus on both Disciplinary Thinking and Student Thinking, as he justified his suggested feedback (ST &DT/J/P.s). Another of his written feedback to Chris’s solution is:

\[
\text{As with Rob, Chris also needs to get involved doing practical work with balls dropping and being projected which would help}
\]
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This aspect. The use of videos/DVDs or applets to help develop the concepts of the independent motion is required.

These comments indicate an attention to Disciplinary Thinking, as he referred to the process of experimenting (DT/P/P.s). Moreover, Mr Jackson justified again his suggested feedback with a focus on both Student Thinking and Disciplinary Thinking. Other written feedback indicated attention being directed to Disciplinary Thinking:

Plain old hard work and repetition through multiple examples/problems is paramount.

Regarding Sue’s solution, Table 2 in Appendix D shows that Mr Jackson generally attended to both Disciplinary Thinking and Student Thinking, in providing feedback. Some instances of his written comments are:

Sue is much the same as Chris with a need to build on the knowledge and confidence.

Practical work and appropriate visual events eg DVD or applets on the computer to reinforce the imagination of the events being analysed. Plain old hard work and repetition through multiple examples/problems is paramount.

In describing the significance of his feedback he indicated the need to “build on the knowledge”, “reinforce the imagination of the events...” which indicates dual attention to Disciplinary Thinking and Student Thinking (ST&DT/P/P.s, ST &DT/C/P.s). Similar to the previous examples, Mr Jackson comments on Rob, and Chris, as in the Sue comments above, also indicate a focus on Disciplinary Thinking, as he referred to “repetition” the problem and the process of problem solving (DT/P/P.s).

General Summary

Generally, Mr Jackson focused on both Disciplinary Thinking and Student Thinking, when providing feedback on all three students’ solutions. He provided feedback that was similar for all three students. His comments overall, indicated a dual attention to both Disciplinary Thinking and Student Thinking, when justifying his suggested feedback to all three students.
Mr Jackson attended to both Disciplinary Thinking and Student Thinking, when providing feedback to Rob’s solution. Mr Jackson attended to both Disciplinary Thinking and Student Thinking, when justifying his feedback on Rob’s solution.

Mr Jackson generally attended to both Disciplinary Thinking and Student Thinking, when providing feedback on Chris’s solution. Mr Jackson had a dual attention to Disciplinary Thinking and Student Thinking, when justifying his feedback on Chris’s solution.

Mr Jackson attended to both Disciplinary Thinking and Student Thinking, when providing feedback to Sue’s solution. Mr Jackson did not justify his suggested feedback on Sue’s solution.

**Formula**: \( v = v_0 + at \)

Table 2 in Appendix D shows that Mr Jackson has focused generally on both Disciplinary Thinking and Student Thinking, when suggesting/ proposing feedback on three students’ explanations of the formula: \( v = v_0 + at \). Mr Jackson stated that the formulae need to be learned.

An excerpt of his interview is outlined below:

*Int: For example do you think, have you thought about ...student had difficulty for understanding this or just you listed these equations for them and then tell them to use it? Usually we do this.*

*Mr Jackson: No, no you can’t do that because then they’ve got – if they don’t have understanding what the equation means how can they use it correctly.*

*Int: Oh, so you try to do..*

*Mr Jackson: If all you’re doing is learning an equation and putting numbers in, that means nothing, but if you’re talking about the physics you’ve got to say what this equation means, what it relates to in the real world... A visual picture... there’s a whole stack of initial learning and then you’re going to combine - it’s a pyramid approach or even an inverted pyramid. You learn bits and then you add together and you get a bigger and better picture.*
The comments referred to the learning process and visualizing. He seems to be referring to a visual model of individual mathematical representation rather than a dynamic one. He referred to “you”, rather than referring to specific student problems or achievements in his verbal comments. The comments attend vaguely to both Student Thinking and Disciplinary Thinking.

Mr Jackson has focused generally on Disciplinary Thinking and Student Thinking, when suggesting/ proposing feedback on Mary’s explanations of the formula: \( v = v_0 + at \). Mr Jackson wrote:

\[
\text{Mary needs to be questioned further over the nature of velocity and speed. She has a good grasp of the idea of a ‘fixed bit’ and a ‘variable bit’ and hopefully she understands these ‘bits’ are both velocity.}
\]

The above comments indicate attention to both Disciplinary Thinking and Student Thinking, as Mr Jackson referred to the student thinking used in the equation (ST/C/Equation). Moreover, this comment indicates a dual attention to Student Thinking and Disciplinary Thinking, when he justified his comment (DT&ST/J/Eq). He also wrote:

\[
\text{The relationship between changing velocity and the vector nature of velocity will need careful thought and quantitative examples since a speed only understanding will lead to real problems with the more advanced concepts such as momentum etc.}
\]

This comment indicates a focus on Disciplinary Thinking, when Mr Jackson referred to the content used in the formula (DT/C/Equation). The comment also indicates a focus on Disciplinary Thinking, when he justified his suggested feedback (DT/J/Equation).

Mr Jackson had focused generally on both Disciplinary Thinking and Student Thinking, when suggesting feedback on Michelle’s’ explanations of the formula: \( v = v_0 + at \). He wrote:

\[
\text{...If she is referring to an object falling under gravity then the velocity should always be increasing at least initially.}
\]
This comment shows that Mr Jackson expected Michelle to think about the content in a way he himself thinks about it, or uses it. This indicates a focus on Disciplinary Thinking, as Mr Jackson referred to the content used in the equation (DT/C/Eq).

However, he added:

Michelle appears to understand the effect on an initial velocity of a force / acceleration.
The concept of acceleration as the change in velocity with time and its vectorial nature is essential for the correct development of concepts such as momentum, same as for Mary.

All the above comments indicate a dual attention to Disciplinary Thinking and Student Thinking, as he referred to the content used in the equation (ST&DT/C/Eq). His justification indicates a focus on Disciplinary Thinking, (DT/J/Eq).

Mr Jackson has attended to both Disciplinary Thinking and Student Thinking, when presenting feedback on Simon’s explanations of the formula: \( v = v_0 + at \). He wrote:

Simon seems to understand the two parts of the equation. As to whether he understands the vector nature is not so obvious.

This proposed feedback indicates dual attention to Disciplinary Thinking and Student Thinking, as Mr Jackson referred to both the content used in, and the process of the use of the equations (ST&DT/C/Eq and ST&DT/P/Eq). When Mr Jackson was justifying his feedback, he wrote:

The concept of acceleration as the change in velocity with time and its vectorial nature is essential for the correct development of concepts such as momentum - the same as for Mary and for Michelle.

Similar to Mary and Michelle, Mr Jackson attended to Disciplinary Thinking, when he justified his suggested feedback (DT/J/Eq).

**General Summary**

Generally, Mr Jackson adopted a dual focus on Student Thinking and Disciplinary Thinking, when providing feedback on Mary’s, Michelle’s, and Simon’s written explanation of the formula. His diagnostic feedback to all three students was similarly
non specific. He focused on Disciplinary Thinking, when justifying his feedback on all three students’ explanations of the formula. The justification he suggested for his feedback was similar for all the students.

**Mr Jackson feedback on two students’ (Karl and Mike) solutions on the Shoved Block task**

Mr Jackson was not able to correctly solve the “Shoved Block” Task. He was reluctant to provide feedback to Karl and Mike. He had difficulty identifying Karl and Mike’s misconceptions. The non specific nature of his feedback to students on non-standard task may have roots in poor conceptual knowledge.

### 4.8 Summary

Based on the aims of this study and in order to explore the research questions, it was decided to use a case study approach incorporating problem centred questionnaires and problem centred interviews about teaching standard and non-standard motion tasks.

The questionnaire consisted of three parts: in the first section, each teacher was asked to solve a standard (Bike) task, and then to discuss and provide feedback on hypothetical student solutions to the task. In the second section, each teacher was first asked to provide a written explanation of their teaching approach for the kinematics formula \( v = v_0 + at \), and then to discuss and provide feedback on hypothetical student explanations of the formula. In the third section, each teacher was invited to provide a written explanation of their background, including qualifications, experience, and teaching areas.

The interview questions were organised into four sections; the first section includes general questions about their choice of their occupation, and their beliefs or views of their teaching of the kinematics topic, problem solving, modelling, and use of formulae in motion tasks. The second section involved requestioning of teaching approaches to solving the Bike task, as well as further questions to teachers about their responses to some questionnaire items which were not clear initially. The questions in the third section concerned teacher approaches to teaching and solving the Glider task, followed by questions concerning teachers’ general ideas about their students’ difficulties in solving the task. The questions in the last section were concerned with the teachers’ approaches for teaching and solving the Shoved Block task, followed by some questions
concerned with the teacher interpretations of, and feedback on, two students’ hypothetical solutions to the Shoved Block task.

Data processing involved two main forms of analyses: the Initial and Comparative. In the initial analysis the data derived from both instruments were tabulated. The Initial Analysis involved coding the teacher responses to the questionnaire interview items, across the Disciplinary Thinking (DT), and Student Thinking (ST) categories. With respect to teacher interpretations of, and feedback on student solutions, the comparative analysis explored patterns or relationships between each teacher’s foci across aspects of the student solutions and motion tasks. This analysis was also used to examine any patterns or relationships among all teachers’ foci across each student’s solution, and each motion task.

The results of these analyses on the data obtained from the eleven physics teachers are presented in the next chapter.
Chapter 5: Results

5.1 Introduction

The research questions of this study were concerned with an exploration of how the teachers of an upper secondary physics subject interpreted, and provided feedback to a range of students’ written solutions to a standard textbook and a non-standard motion task, and to students’ written explanations of the formula $v = v_0 + at$. Since this study involved exploration of teachers’ intentions when commenting on student difficulties in understanding linear motion, it was important to investigate the teachers’ beliefs about the learning of motion, and the approach they used for teaching motion tasks.

As explained in the previous chapter, in order to address the research questions, a Problem Centred Questionnaire (PCQ) (Appendix A) included the Bike task which is a standard problem was used. Teacher responses to the questionnaire were further explored during the PCI. The interview involved two additional physics problems: the Glider task which is a standard problem in the context of VCE physics that included algebraic symbols rather than numbers (Appendix B), and the Shoved Block task (Appendix B), which is considered a non-standard task, because the physics curriculum in Year 11-12 in Victoria, Australia does not include this qualitative type of task.

As explained in Chapter 4, two consecutive analyses, the Initial and Comparative, were used to analyse the data derived from all the instruments. The Initial Analysis involved coding the teachers’ responses to the questionnaire and interview items, across Disciplinary Thinking (DT), and Student Thinking (ST) categories. The comparative analysis explored patterns or relationships between each teacher’s perspective across aspects of the students’ solutions and motion tasks. This analysis was also used to examine any pattern or relationship between teachers’ perspectives across each student solutions and each motion task.

The focus of this chapter is on reporting results from the Initial Analysis, and the patterns or relationships derived from the Comparative Analysis. The data obtained from the physics teachers will be reported in four sections. Teachers’ backgrounds derived from the third part of the questionnaire are reported in section 5.2. This is followed by teacher beliefs about teaching and learning in section 5.3. Teacher interpretations of student solutions are outlined in section 5.4. Teacher feedback on
student solutions is explained in 5.5. Finally, a summary of the results will be briefly presented.

5.2 Teachers’ backgrounds

5.2.1 Demographic information

Data about the teachers’ backgrounds were collected from the third part of questionnaire and the interview. Table 5.1 outlines teachers’ experience and areas of teaching.

Table 5.1
The teachers’ experience and areas of teaching

<table>
<thead>
<tr>
<th>Teacher’s name</th>
<th>Teaching experience</th>
<th>Teaching area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-3 years (years)</td>
<td>9-16 years (years)</td>
</tr>
<tr>
<td>Ms Jenkins</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td>Mr Jackson</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ms Johnson</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td>Mr Robinson</td>
<td>√</td>
<td>-</td>
</tr>
<tr>
<td>Mr Geraldton</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td>Mr Peterson</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td>Mr Pierce</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td>Ms Chick</td>
<td>√</td>
<td>-</td>
</tr>
<tr>
<td>Ms Jones</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td>Mr Sadler</td>
<td>√</td>
<td>-</td>
</tr>
<tr>
<td>Mr Richardson</td>
<td>-</td>
<td>√</td>
</tr>
</tbody>
</table>

Note: VCE = Victorian Certificate of Education, maths = mathematics, phy = physics. Sci = science

The teaching background of the teachers in this study is typical of physics teachers in the state of Victoria, Australia. The teachers all taught VCE (i.e. year 11 and 12) physics. The next subjects most commonly taught by teachers in the study are VCE mathematics, year 10 science, and mathematics, respectively. Of all the physics teachers, Mr Jackson was the only teacher who taught two VCE mathematics subjects (Mathematics Method and Specialist Mathematics). Mr Pierce commented that he had avoided teaching any mathematics at VCE level during the last 10 years. He considered that teaching Physics and Mathematics subjects simultaneously for the VCE would cause him to teach physics topics in a mathematical way and not with a conceptual approach.
5.2.2 Teachers’ content knowledge/competencies in solving the non-standard motion task

In order to explore some aspects of teachers’ PCK, the teachers’ CK level in the motion area were examined. By investigating their personal strategies in solving two standard tasks (Bike and Glider), and a non-standard task (Shoved Block), teachers’ CK levels were classified into three levels: high, medium, and low. This classification was based on an exploration of the teachers’ conceptual understandings of motion concepts and the process of problem solving they employed for three tasks. These categories are shown in Table 5.2.

Table 5.2
Teachers’ content knowledge in motion area

<table>
<thead>
<tr>
<th>Different levels of CK</th>
<th>High</th>
<th>Medium</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N= 5</td>
<td>N= 1</td>
<td>N= 5</td>
</tr>
<tr>
<td>Teacher’s name</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mr Peterson</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ms Jenkins</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ms Johnson</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Ms Chick</td>
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<tr>
<td>Mr Robinson</td>
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<tr>
<td>Mr Pierce</td>
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<tr>
<td>Mr Geraldton</td>
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<tr>
<td>Mr Richardson</td>
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<td>Mr Jackson</td>
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<td></td>
</tr>
<tr>
<td>Ms Jones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mr Sadler</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: N= Number of teachers.

Five teachers were able to solve the non-standard (Shoved Block) task. These teachers were classified as having a high level of CK. However, five other teachers were unable to solve the non-standard task and some of them (e.g. Mr Geraldton and Mr Sadler) were unaware of their own low level of CK. Mr Pierce was not confident about his correct answer to the non-standard task, and he frequently changed his answer. Mr Pierce’s CK was classified as medium.

All teachers solved the standard (Bike) task, correctly. First, they identified what was unknown, then chose the appropriate formula and substituted the symbols with numbers and obtained the correct answer when solving the task.

All teachers also solved the other standard (Glider) task, correctly. However, some teachers found the use of the algebraic form of the question challenging. For example,
although Mr Geraldton solved the Glider task successfully on his second attempt, he appeared to lack a deeper understanding of the content. In other words, it seems that he may have a limited CK, as represented by the initially unsuccessful attempt to solve the problem and as conveyed by his interview response regarding his failure to succeed in the first attempt (see section 5.3.3).

As already noted, out of eleven teachers, only five (Mr Peterson, Mr Robinson, Ms Jenkins, Ms Chick, and Ms Johnson) solved the non-standard task successfully. It has to be acknowledged that it is possible that, although the teachers who did not solve the non-standard task appeared to have a weak background in the area of the non-standard task, they may have had high content knowledge in other fields of Physics. However, considering the length (9 - 20 years) of the teachers’ experiences (Mr Pierce, Mr Richardson, Mr Geraldton, Ms Jones, and Mr Jackson) in teaching physics, it seems likely that they were able to solve only the standard tasks successfully because they had taught these tasks for a long time, and had often seen them explained in text books. This is consistent with some literature (Arzi & White, 2008) that shows teacher subject matter knowledge does not necessarily develop over time or with experience in teaching (see Chapter 3).

5.3 Teachers’ beliefs

An important part of this study focused on aspects of teaching and learning problem solving. Teachers were asked (see Appendices A and B), to provide their general beliefs about the characteristics of a good physics teacher, reported below in section 5.3.1. Teacher beliefs about general learning difficulties encountered in the motion topic are discussed in section 5.3.2. Teacher beliefs about teaching and learning specific aspects of motion are explained in section 5.3.3. Through the comparison and analysis of all relevant teacher responses regarding teaching and learning linear motion, teacher beliefs are categorised in section 5.3.4.

5.3.1 General beliefs about the characteristics of a good physics teacher

As explained previously (Chapter 4), teachers’ responses to the third part of the PCQ were further explored during an interview, in terms of their choice of, and success in, their occupation, as well as their general ideas about teaching and learning the motion topic. The foci of each teacher’s response that are identified and discussed are illustrated by some underlined excerpts (which indicate the researcher’s emphasis) on teachers
written and oral comments in this chapter. It should be noted that as explained in Chapter 4, section 4.4.3, step 7, these excerpts can be a word, phrase, sentence, or a paragraph or whole teacher comments to a student. It was possible to give a label to a teacher by looking across all teacher comments. The complete categorisation of teachers with respect to their beliefs is discussed in section 5.3.4.

The following discussion considers the variety of teachers’ beliefs about the characteristics of a good physics teacher.

Ms Chick’s comment when responding to the questions: “What do you think makes a good physics teacher? Which capability do you consider to be essential and why?” is given here:

*Firstly you have to really understand the physics because you need to know much more than you’re teaching otherwise you can’t explain it and you don’t know why certain things are important and certain things are not as important.*

This shows that Ms Chick’s priority for being a good teacher is having high CK, which indicates a focus on formal concepts. She also added:

*I think you have to be very good at simplifying things using short sentences, using diagrams, to make it easier for the students to understand. I know that with my students, especially motion, they think they know what a word means but it means something slightly different when we use it in the physics sense. So to be able to simplify things and make it obvious what a word like acceleration actually means is very important. So simplifying, knowing the content, and being able to get across to the kids. Good communication with kids I think is very important.*

Ms Chick introduced the activities using short sentences in order to make the content “easier for the students to understand” (see underlined sentences). These factors show her perspective or beliefs related to/focused on student thoughts.
Mr Robinson, in response to the same question, stated:

*A good knowledge of physics is vital. The best physics teachers I’ve seen are funny, a sense of humor. I think it’s a good way to engage with the kids*

*Int: Fun, have fun you mean ...?*

*Mr Robinson: Yeah, and... to be able to put yourself in the shoes of the students... so to have empathy with the students to be able to pick up when they’re really stuck even if they don’t say they’re stuck and to try and ask the right questions to find out what they’re confused about or to what level do they understand and where is it that they’re sort of losing the plot or losing the line of logic, so being able to ask good questions. They’re the main things.*

This shows that Mr Robinson considers that a good physics teacher asks good questions to understand his students’ learning and difficulties, so he can provide feedback that is appropriate to his students’ needs. Mr Robinson appeared to search and explore his students’ thinking (see underlined phrases). In addition, he explained the need to be engaged with students - termed by him as “a sense of humour” (see the first underlined phrase).

An excerpt of Ms Jones’ interview in response to the question concerned with describing a good teacher is:

*like having rapport with student like being able to communicate with whatever age group you’re teaching... You could have good communicators but if they don’t know the subject area then they’re not going to be able to teach that well either because they don’t have the background knowledge so it has to be a combination of both. So I think there needs to be ... an ability to communicate that knowledge with the age group that you’re teaching...and passion, I think you have to be passionate, you have to want to do it because otherwise you’re just gonna be boring and the kids won’t want to listen. Passion or emotion, I think all that comes in there as well.*
It is interesting that although Ms Jones emphasised the need for teachers to have good content knowledge to be good physics teacher, she was classified as having low content knowledge (Table 5.2).

Mr Peterson explained the characteristics of a good teacher as follows:

*Mr Peterson: Somebody who really enjoys the subject in its own right ...*

Mr Peterson considered that enjoying the subject is a characteristic of a good physics teacher. In other excerpt of his interview, he stated:

*especially in my part of the school the psychologist would say boys, and girls for that matter ... learn teachers, they don’t learn subjects. And ... lots of people who might say I hated mathematics or I can’t do mathematics, and it was nothing to do with their ability, it was they hated the teacher.*

This comment mentions that it is important for students to like their teacher. Mr Peterson focussed more on this aspect of a teacher, rather than the teacher capacity to address individual differences in students’ abilities in understanding the content or topic. This is supported by his other comments and beliefs about a approach to teaching the motion tasks and the formula $v = v_0 + at$ (see section 5.3.3).

On the other hand, some teachers such as Mr Jackson provided general comments about being a good teacher:

*Someone who’s curious about all sorts – you’ve got to be curious about all sorts of things, you want to know why things are the way they are, why things work the way they work. You’re sort of one of these people that – you’ve been the despair of your parents because you took things apart all the time, you never put them back together again but you took lots of things apart ‘cause you were interested in why they worked. You’ve got to be interested in all sorts of things, you’ve got to be a curious person, that’s not a strange person but a person who’s curious.*[laugh]

Mr Jackson pointed to being curious as a characteristic of a good physics teacher.
To summarise, the comparison and analysis of all teachers’ responses showed that there were a variety of beliefs and comments regarding to the characteristics of a good physics teacher. While some teachers had a focus on student needs, or individual differences in student needs for understanding motion (e.g., Mr Robinson), some had an emphasis on teacher CK (e.g., Ms Jones), or a focus on understanding motion content. (e.g., Ms Chick) It was also found that some teachers focussed on the role of the teacher in teaching motion (e.g., Mr Peterson).

5.3.2 Teachers’ beliefs about general learning difficulties encountered in the motion topic

With regard to difficulties in teaching the motion topic, examples of teachers’ responses included the following:

Ms Jones explained the general difficulties, as seen here:

Yeah, I think motion’s a difficult one because they come in with a lot of misconceptions from prior learning or lack of learning. I probably sound very critical of teachers in middle school. I think because we try and teach some concepts that are difficult at lower year levels and the teachers maybe don’t really have a good concept of it themselves, so they try to go further than what their knowledge is. So a lot of students come into Year 11 physics with things that you have to unteach, you know, there’s misconceptions that you have to overcome. And motion seems to have a lot more of those than some of the other topics probably because the other topics haven’t been touched on. So they have sort of no knowledge of some of the other topics, whereas with motion there’s a lot of misconceptions.

Ms Jones considered her students’ misconceptions or “pre-instructional” knowledge as her main difficulty in teaching the motion task.

On the other hand, Mr Jackson thought teaching motion was easy:

It’s relatively easy because everybody moves and they’ve all experienced motion, so it’s one of those things that they live in a moving world so they have some idea about how things move
It seems that Mr Jackson thought teaching motion was easy because he believed that students already have “some idea about how things move” (see underlined words).

With regard to students’ difficulties in understanding motion formulae, most teachers believed that students have difficulty. An excerpt from Ms Jones’s interview exemplifies this:

*For the average student [the formulas are] probably difficult because they don’t like algebra. So as soon as they see formulas a lot of them throw their hands in the air and go I can’t do this, it’s algebra, I can’t manipulate an equation, I don’t know what to do. And so that’s why you have to go through it very carefully so that they can see that they can do it.*

This shows Ms Jones believes that her students have difficulties using and manipulating the kinematics equations because of the algebraic form of the formulae.

However, Ms Chick explained her students’ difficulties more specifically:

*It’s very easy to teach them the steps, it’s very easy to teach them look for the numbers, put the numbers in the equation, get an answer. It’s hard to teach them what those equations mean and it’s hard to give them the conceptual background. The actual use of the equations is simple but the understanding behind the equations is very hard.*

This indicates Ms Chick’s beliefs about her students’ difficulties in understanding the equations. Ms Chick’s comment also indicates that her priority is for her students to understand the equation rather than just learn how to manipulate and memorize it.

The above comments and evidence are derived from teachers’ responses to general questions concerned with teaching and learning physics/motion. A further analysis on teachers’ comments on teaching and learning the specific aspects of motion tasks and formulae was also conducted, to be explained in section 5.3.3.

### 5.3.3 Teachers’ beliefs about teaching and learning specific aspects of motion

Each teacher was asked for their comments on their teaching approach to the standard and non-standard tasks and the formula \( v = v_0 + at \). The analysis of the teachers’ comments provided an initial picture of their values and intentions in teaching a
problem solving strategy, and teaching the use of the formula, when conveying and communicating ideas about motion with their students in the physics classroom. Teacher beliefs about teaching and learning motion tasks and the physics formula \( v = v_0 + at \) are explained below.

**Teachers’ beliefs about teaching and learning motion tasks**

As explained previously, each teacher was asked to explain their approach to solving and teaching two standard (Bike and Glider) tasks, and one non-standard (Shoved Block) task. The teachers were also asked about the difficulties encountered in the teaching and learning of these specific tasks. Compared to Bike and Shoved Block tasks, the data derived from the Glider task provided less insights for exploring the teachers’ beliefs about teaching and learning. This will be briefly explained in Chapter 6, section 6.6.3.

<table>
<thead>
<tr>
<th>Fred is riding his bike on a level road at a speed of 5.0 m ( s^{-1} ). The tail-light breaks off. It takes 0.45 seconds to reach the ground.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mary was watching Fred and saw the tail-light fall. Her view of the events is shown in the Figure below.</td>
</tr>
<tr>
<td>How far above the ground was the tail-light when it was attached?</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>Fred was at position A when the tail-light broke off, and at position B when it hit the ground.</td>
</tr>
</tbody>
</table>

*Figure 5.1: The Bike task.*

Figure 5.1 shows the Bike task, considered a ‘standard’ task. While all teachers solved the Bike task correctly, they used a procedural or algorithmic approach to obtain their solutions.

When explaining her approach to solving and teaching the task, Ms Jones said:

\[
\begin{align*}
I \text{ would always say to my students write down the information you have and I would include in that write down what are you trying to find, and so I would actually have my students write that I’m finding vertical distance, so I’m not just finding}
\end{align*}
\]
distance I’m finding vertical distance, so I have to determine from this question how far above the ground, how far above the ground means how far does it fall.

It seems that the core of Ms Jones’s instruction is based on rehearsed algorithms. This is part of the routine strategy used to solve and teach physics problems: writing known and unknown quantities, and then working through different equations to finding the unknowns. This strategy was labeled by Redish (1994) as the “Dead Leaves” approach, and he proposed that this teaching strategy is not appropriate for improving student learning in the physics context (see Chapter 2).

When commenting on teaching the Bike task, some teachers, in addition to their routine teaching, focused on visualising the situation, doing experiments, or predicting the answer. For example, Mr Jackson stated:

I teach the students to say OK read the question, visualize, underline the things, the information that you’re given, it started at rest or it was dropping under gravity and then you can write down. OK the time is 0.45, the initial velocity is zero, your acceleration is 10. One thing I noticed they haven’t defined up or down as being positive or negative. So they’re standard ways that you deal with these sort of problems. It comes about the fact that I’ve taught them both from the physics side and from a mathematics side.

This approach includes visualising the situation of the object, and is presumably an attempt to encourage students to link the motion task to their real world experience.

The second standard task (the Glider) is shown in Figure 5.2. Each teacher was requested in their interview to provide an explanation about their approach to solving and teaching the Glider task.
The mass of glider A is one-half that of glider M (i.e. \( m_M = 2m_A \)). Apply Newton’s second law (\( F_{net} = m\Delta v/\Delta t \)) to each of the colliding gliders to compare the change in momentum (\( \Delta p = m\Delta v \)) of gliders A and M during the collision. Discuss both magnitude and direction. Explain.

Figure 5.2: The Glider task.

The Glider task was considered a ‘standard’ task. Although all teachers eventually solved the Glider task, some had difficulties. With respect to their approach to teaching the Glider task, most teachers substituted some numbers into the algebraic symbols; i.e. to solve the Glider task, they assumed numerical values for the concepts involved. It seems that the difficulties some teachers had in solving the task were mainly due to the symbols and the diagram used to solve the task. Mr Geraldton had some difficulties in solving the Glider task. It seemed that he may have a limited CK as represented by his initially unsuccessful attempt to solve the problem and as conveyed in his interview response to a question regarding his failure to succeed in the first attempt:

\[
\text{As there is not any number in this task, I have got a struggle with that...students would have this difficulty too.}
\]

This shows that Mr Geraldton believed that his students were likely to experience similar difficulties to those he had, which for him were due to the absence of numbers in this task. The above claim of limited CK was further validated by his failure to solve a non-standard (Shoved Block) motion task (described later).

Similarly, Mr Jackson considered the algebraic form of the question as a difficulty for students. Excerpts of his interview elaborate this:
This is going to be difficult because the mathematics is – the symbolism is difficult. OK, you’ve defined things with subscripts with subscripts so $VA_{subscript}$ with an initial below that again a subscript with a subscript [i.e. $v_{A_{i}}$], so again it all becomes messy.

Int: you mean, if we classify students’ difficulties, first of all you mean...because there isn’t any number in this ...

Mr Jackson: Correct, it’s not numerical. [the second difficulty in this task is] the fact that this won’t happen, the light one will hit the heavy one, if this is twice as heavy this is not going to stop, this is going to rebound.

Int: [object] $A$?

Mr Jackson: Yeah, $A$ will rebound in reality. ... if you do it in reality this one, the light one hitting the heavy one will rebound, it’ll end up going back the other way. So this is not a real – this is mathematical construction, not a real picture.

Mr Jackson also believed that students would have difficulty with this task, because the task does not represent real life and in reality the event would not happen.

However, Mr Peterson did not believe that his students would have any difficulty in solving this task, as he stated:

*I don’t believe many of my students would have any problem to solve this task... out of 50, the majority can solve the task with numbers or without [numbers]...*

Since Mr Peterson understood this task, he supposed that his students would also understand it. His comments could also be due to the fact that he was very confident in his teaching approach to help his students’ understanding, or that he was drawing on his personal experience of successfully using this type of task in his teaching. It is of interest to note that Mr Peterson, Mr Jackson, and Mr Geraldton were teaching in the same high school.

Mr Robinson stated in his interview, when commenting on teaching the Glider task:

*In solving it for students I would probably break it down into looking at – I’d probably draw a box similar to this and I have*
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this system where we always talk about momentum being conserved in a closed system. So I would draw a box around the two to show that it’s a closed system and talk briefly about we can ignore friction and things like that...ignore the friction, but the glider’s on an air track or whatever so the friction is very low and we can neglect it. It probably would just go straight. I mean it says here to use Newton’s second law but I would probably go with just conservation of momentum and say we’ve talked about momentum always being conserved. In our initial system glider A has got momentum given by that and we don’t know what $V_A$ is but it’s just a number and we don’t know what the mass is but it’s just a number so we’ve got that much momentum. Glider B has no momentum because it’s stationary ’cause we’re told that in the problem.

As can be seen in the above quote, Mr Robinson, unlike some of the other teachers, did not substitute the symbols with numbers, but continued to talk about them as symbols (See the underlined words). Interestingly Mr Robinson had a high CK, as noted earlier. It should be noted that as there was not a rich data derived from the Glider task, the relevant findings are briefly discussed in Chapter 6, section 6.6.3.

In the last part of the interview, each teacher was asked to solve and explain their approach to teaching the non-standard (Shoved Block) task, as shown in Figure 5.3.
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.

(Source, Sherin, 2001, p. 488)

Figure 5.3: The Shoved Block task.

The Shoved Block task was considered to be a ‘non-standard’ task. The correct answer for the Shoved Block task is: “both blocks travel the same distance”. As explained previously, out of eleven teachers only five solved the Shoved Block task correctly. Of those who solved it, three teachers (Mr Robinson, Ms Jenkins, and Ms Chick) used formulae and solved the task. Mr Peterson solved the problem through two ways: using the formulae and using his common sense. Ms Johnson had a conceptual approach and used less mathematics when solving the task.

The teachers who were not able to solve the non-standard task demonstrated some misconceptions when explaining their approach to teaching the task. All of these teachers except Mr Geraldton and Mr Sadler were unsure about their suggested response to the Shoved Block task. Notably, Mr Geraldton conveyed the impression of having confidence in his (unsuccessful) solutions to the non-standard task. He stated:

... Generally if I would go to teach that I will go through it this way. It is not that much more difficult to teach, we actually do it in Year 10, and I can’t derive the coefficient friction from the graph of the friction of force against normal force.

There appears to be a gap between what Mr Geraldton can do and what he thinks students can do, and this is reflected in his teaching approach and reflects on his PCK.

In the interview with Mr Sadler I asked:
Int: how do you solve and teach this [shoved Block] task?

Mr Sadler: ... if it’s on a level table not a slope then this is gonna be equal to the weight, so the lighter block is going to have a smaller value of that which is going to have a smaller value of that which is therefore going to have a smaller value of that, so for the lighter block friction will be less. So for the lighter block friction is going to be less, and if the friction is going to be less then it will travel further.

Figure 5.4: Mr Sadler’s use of the mathematics to solve the Shoved Block task.

Mr Sadler could not correctly solve the Shoved Block task. He attempted to employ a mathematical axiom in Figure 5.4 that includes friction and will provide the answer, but the formulation is at best heuristic and does not contain the variables he is considering. His formulation of friction in the movement of each block does not consider it as a function of force per unit area in each block and therefore identical. His
problem solving strategy would not have been meaningful to high school students. His description of his approach to teaching this task was as follows:

\[ \text{Int: And how do you teach [the shoved Block task] to a student?} \]

\[ \text{Mr Sadler: If we had to teach this and it's not in the Study Design but if we're gonna teach this then we would do it, it's an easy thing to do... first I would say what things could affect the frictional force, and the pupils would say the mass of the block, some would say the area in contact with the table, some would say the material of the block, how smooth or rough it is, OK. So then we'd say well let's try ... let's vary one at a time by experiment and see what does affect it. And so firstly one experiment they'll do they'll vary the mass. One experiment they'll do they'll vary the area. One experiment they'll do they'll vary the surface, so they'll vary material they use. ... But the conclusions they draw would show that the mass clearly does affect the distance it travels, and the surface clearly does affect, and at that point we say well OK so then we're going to have to say well if the frictional force depends on these two things, and then I'd introduce them to the equations to justify what they've done.} \]

Similar to Mr Geraldton, the teaching of the Shoved Block task was not considered to be difficult by Mr Sadler. His strategy for teaching about the Shoved Block task is empirical but limited by his (lack of) content knowledge in this area. This poor content knowledge is reflected in the absence of strategy for heuristically using a mathematical representation to explain and predict the outcome or solution to the problem.

**Teachers’ beliefs about teaching/learning the formula** \[ v = v_0 + a \]

In the second part of the questionnaire, each teacher was asked to provide a written comment about teaching the formula: \[ v = v_0 + a \]. The most common approaches identified for teaching the formula comprised: putting the formula in a context/an example or applying a direct approach to teach the elements of the equation. Although the focus of some teachers’ comments for teaching the formula was on student thoughts
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and needs or individual differences in the student needs for understanding the use of the formula, some teachers only focussed on the content and their use of the formula.

For example Ms Johnson wrote, when commenting on teaching or introducing the formula $v = v_0 + a$ :

*I would start with posing a problem that is familiar and accessible (eg: bike rides at 5 m/s, accelerates at 2m/s$^2$ for 3 seconds, how fast is he going now? ) and get people to answer it. If they have different answers I would get a few people to explain their thinking and see if we have agreement. Once most people agree, I would set one or two more and get them to solve, and then generalize about the process. Once they can generalize about what they are doing, I would write/speak it in words and then introduce the algebra as a simple representation of this thinking ie: initial conditions and then a change in this speed due to the acceleration...... I'd give them a problem, get them to work in groups, come up with a solution which they normally can do, then get them to talk about what their understanding is. Before I tell them anything I want them to articulate it to me. That way when they are doing that if there’s an error I’ve got something to work with. And if there’s not, then we can just build it up and they get the sense at the end of the lesson that that’s something that they knew or developed or whatever themselves and that we can then use that.*

These comments indicate two important issues on which Ms Johnson focused. First, she wanted to involve the students in group discussion rather than just ask them to do some experiments or other activity such as problem solving. That is, she focussed on student thoughts (see underlined sentences). Second, she provided specific comments rather than explaining general comments. For example, she considered some possibilities for students’ discourse and their misunderstandings in the classroom, and then justified different situations. In particular, she also used some adverbs such as “before” or “once” which shows her priorities for encouraging a logical approach to problem solving. Ms Johnson referred to a specific way to represent the formula, that is “write... it in words” which may show her skilled knowledge and beliefs about
representing and responding to student difficulties. These remarks indicate a disposition
to respond to student needs, within an appropriate approach to teaching advancing
students’ learning in motion and this seemed to be consistent with the notion of
meaningful problem solving explained in section 3.1.2.

When explaining her approach to teaching the formula \( v = v_0 + a \) Ms Chick wrote:

\[
\text{Begin by discussing graphs of motion with constant acceleration. Discuss what the gradient of a velocity time graph is by looking at the units involved. Connect the equation to a straight line } y = mx + c \text{ to this particular situation, substitute } v, \ v_0, \ a \text{ and } t \text{ into the straight line equation.}
\]

\text{After showing the equation mathematically, discuss the concept of acceleration as a change in velocity over a time period and how the change of velocity can be found from the acceleration. Discuss the fact that the final velocity will be the initial velocity plus the change in velocity, found from the acceleration. The first approach caters to more mathematical students while the second is a more conceptual approach. Both strategies need to be used to cater to both types of students and to enhance the understanding of both types of students by showing them other ways to look at, and understand the situation.}

It seems that Ms Chick’s priority is to respond to different prior understandings in
her students’ uses of mathematics and physics concepts when teaching the formula.
These comments can be seen as a logically grounded approach to understanding
mathematical modelling of linear motion, rather than representing a general idea about
responding to student needs and theoretical representation. Ms Chick’s language and
practices are effectively unified.

However, Mr Peterson’s strategy in teaching the formula: \( v = v_0 + a \) indicates he
is focusing on explaining different motion contexts in a graphical form. This is outlined
in Figure 5.5.

Mr Peterson references a set practical exercise in the Physical Science Studies
Committee (P.S.S.C) (Turner, 1984) materials using ‘ticker tapes’. This strategy for
teaching the formula uses traditional tactics related to the use of graphs and mathematics, and appears to omit the analysis of qualitative concepts that is an important feature of meaningful problem solving (explained in section 3.1.2).

Mr Peterson clarified his written response to the question in Figure 5.5 in the following interview excerpt:

*I like to use graphs instead of equations in my teaching. Why I like to do graphs is that these things are really only based on, you know, situations like this …”*

It seems that Mr Peterson liked to teach using graphs as he himself had learned and understood the kinematics equations by using graphs. He continued to justify and to defend the use of graphs for teaching equations as follows:

*Int: some people [in the literature] believe that interpreting a motion graph is difficult for students, what do you suggest? Mr Peterson: if that’s true then I would ascertain that that’s bad teaching, in the same way some of the misconceptions in science whether it’s motion … is bad teaching because they haven’t taught the basic concepts…. Now I reckon our kids would have a very good understanding of graphs because we’ve done them, and I would always insist ...*

It seems that Mr Peterson placed more emphasis on attending to his presentation of ‘good teaching’ than on attending to understanding students’ difficulties in interpreting/understanding graphical representations. It appears that the beliefs of Mr Peterson are consistent with Redish’s (1994) argument that teachers teach physics in a way that they themselves understand and enjoy.
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Figure 5.5: Mr Peterson’s approach to teaching the formula: \( v = v_0 + at \)

In contrast to Mr Peterson who believed that understanding a graph would be easy for students, Ms Johnson stated the following, when explaining her students’ difficulties in motion tasks:

*Int: when they solve some problems in physics, when they go to a new physics problem, or motion problem ..., sometimes they*
can’t solve it in the new context. What is the source of this difficulty?

Ms Johnson: ...Often I find here that girls engage well in class but then they’re not prepared to go away by themselves and think through it again or apply through it again or, you know, start to make it their own. That maturity, you know, maturity when you’re studying.

The kids that I teach have more trouble with the graphs than they do with the equations, so interpreting motion on graphical things they find harder. So I spend a fair bit of time on that but that’s the bit they find harder than equations. But it’s still only stuff that they should’ve done in year 9, you know, gradients and areas.

While Mr Peterson believes his logical graphical representation of the experimental observation provides access for all students to the grammar of physics, Ms Johnson draws on the authority of her experience of difficulties her girl students have with the logic of such graphical representation.

To summarise, Ms Chick and Ms Johnson were the only teachers who believed it was necessary to focus on tackling student difficulties with understanding the mathematics, such as mathematical formulae and graphs, when teaching the formula.

5.3.4 Categorising teachers’ beliefs about teaching and learning motion

Considering the results of 5.3.1 - 5.3.3 together and through the comparison and analysis of all relevant teachers’ responses, three groups with specific views, regarding learning and teaching linear motion were identified:

Group 1: (Ms Johnson, Mr Robinson, Ms Chick, Mr Jenkins, Ms Jones, Mr Pierce, Mr Richardson, Ms Jenkins)

These teachers’ attitudes or beliefs about being a good teacher of physics appeared to be based on the importance of student understanding and interaction with the formal discipline of physics or motion tasks. Some of these teachers (Ms Johnson and Ms Chick) also thought it important to focus on and anticipate student needs and difficulties, indicating their awareness of individual differences in student thinking, and the common sense understandings that students applied to the linear motion tasks.
The beliefs of the teachers in this group are consistent with the view of good teaching that underpins the framework of this thesis, as outlined in Chapter 3. On this basis, we might expect that these teachers’ beliefs be reflected in their practice so that their interpretations of student solutions to linear motion tasks and the student feedback they provide, which is discussed later in this chapter, fall into both the Student Thinking and Disciplinary Thinking categories. The actual categorisation for these teachers is discussed in sections 5.4 and 5.5.

Group 2: (Mr Peterson)

The priorities of this teacher for being a good teacher using linear motion tasks appeared to be focused on his own beliefs and interests in teaching problem solving, rather than the needs of the students. For example, when explaining student difficulties in motion, this teacher mainly focused on his own beliefs about his successful systematic teaching of the formal representations of linear motion. He did not believe that his students would have difficulty if the instruction was systematic in a way that he described. This notion was illustrated in his approach to teaching motion tasks or the formula: $v = v_0 + at$. His comments consistently assert the power of the traditional empirical-logical teaching approach. Thus, we might expect that this teacher would fall into the Disciplinary Thinking category when interpreting student solutions to motion tasks and providing feedback. Again, the actual categorisation is discussed in sections 5.4 and 5.5.

Group 3: (Mr Sadler, Mr Jackson)

Although their comments can be interpreted to be inclined to as having the focus of either group 1 and 2, their written and oral comments were very general and vague, which distinguish them from the other two groups.

5.4 Teachers’ interpretations of student solutions

Each teacher’s interpretation of three student solutions to the Bike task (standard), three student explanations of the formula $v = v_0 + at$ and two student solutions to the Shoved Block task (non-standard) were analysed across Disciplinary Thinking (DT) and Student Thinking (ST) categories (refer to Chapter 4). An in-depth analysis of each teacher’s written explanation about the individual student solution and their relevant discussion in the interview were used to establish a clear picture of the teacher’s response. Since there were different amounts of texts from different teachers in the
interview and questionnaire, the focus of each teacher comments were reduced, coded and then summarized in Appendix D.

The foci of each teacher’s response that are identified and discussed are illustrated by some underlined excerpts (which indicate the researcher’s emphasis) on teachers written and oral comments in this chapter. It should be noted that as explained in section 4.4.3, step 7 of the qualitative content analysis; these excerpts can be a word, phrase, sentence, or a paragraph or whole teacher comments to a student. It was possible to give a label to a teacher by looking across all teacher comments.

A comparative analysis was conducted to identify the patterns or relationships between teachers’ interpretations across the students’ solutions and the types of motion tasks. In order to address the first research question, concerned with investigating teachers’ interpretations of student solutions, it was important to explore the differences and similarities between the teachers’ responses with respect to the types of student solutions; that is, the students’ correct or incorrect solutions (see section 5.4.1), and types of tasks - standard or non-standard (see section 5.4.2). These are explained below, respectively. Teachers’ interpretations of three students’ explanations/understandings of the equation \( v = v_0 + a \) also will be explained in section 5.4.3.

The teachers’ interpretations are categorised approximately across Student Thinking and Disciplinary Thinking in the tables throughout section 5.4. These categorizations explore teachers’ interpretations of only two students’ (Chris, Rob) solutions to the Bike task, teachers’ general foci on three students’ (Mary Michelle, Simon) explanations of the formula \( v = v_0 + a \), and teachers’ interpretations of only one student (Karl) solutions to the Shoved Block task.

### 5.4.1 Categorization of all teachers’ interpretations with respect to the student solutions

Part of the PCQ and PCI items addressed the research aim of exploring the different ways teachers respond to a student’s correct and incorrect solutions to the motion tasks. As explained in Chapter 4, analysis of the teachers’ interpretations of the student solutions or approaches revealed that teachers’ thinking or intentions could be described as having a focus on Disciplinary Thinking (DT), or Student Thinking (ST), or a focus on both Student Thinking and Disciplinary Thinking.
With respect to teacher focus that fell into the Student Thinking category, it seems that a teacher’s comments are a consequence of his/her interaction with a student’s explanation and thoughts. In fact, the teacher attended to each surrogate student’s thinking when diagnosing the source of the student’s learning or misconception. Some examples of the teacher’s interpretations that were Student Thinking focused included judging and analysing the student’s understanding of the content used in the problem solving strategy or in formulae, identifying the student’s learning of the process of problem solving or the use of the formulae, and diagnosing the source of the student’s understanding or misunderstanding.

However, with respect to teacher responses that fell into the Disciplinary Thinking category, the focus, when diagnosing the source of the student’s success or error, was on reporting or re-presenting each student’s performance, rather than on student’s thoughts. Some examples of the teacher interpretation that indicated a focus on Disciplinary Thinking were: reporting the student’s use of the content used in problem solving strategy or in formulae, the process of student’s problem solving or use of the formulae, and diagnosing the source of error or success in student’s performance rather than their learning.

Some teachers’ written and verbal comments that exemplify the Student Thinking, Disciplinary Thinking, or both Student Thinking and Disciplinary Thinking foci are explained throughout this chapter.

*Teachers’ interpretations of Chris’s (correct) solutions to standard task*

Each teacher was asked to discuss Chris’s solution to the standard (Bike) task. Chris’s verbal explanation and written solutions to the Bike task is detailed in Figure 5.6. Figure 5.6 shows Chris’s correct solution to the Bike task, which indicates an appropriate understanding of the formulae in the context of the question.

A detailed analysis is presented in Appendix D of each teacher’s attentions and foci across the solutions of three students (Chris, Rob, Sue) to the standard (Bike) task, three students (Mary, Michelle, Simon) explanation of the formula \( v = v_0 + at \), and two student (Mike and Karl)solutions to the non-standard (Shoved Block) task.
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Chris: Firstly I was reading [the problem], then I needed some formulas. Then I'm thinking horizontal 5. No it is vertical so ignore the five that was my next bit of thinking.

Int: Did you go quickly to this equation, or.

Chris: No then I thought so it is vertical, where? what?, how it starts?. Then where? what how it changes. So that bit [indicating “movement caused by g”] is really here [draws an arrow to “Where/what/how it starts and Where/what/how it changes”]

I thought, aha, it is only vertical the motion I am looking for a distance. I have to know something about where I started and since it is a vertical distance, I know that … acceleration is going to take effect so I know there is going to be something related to where I started which is not given by the distance but it is given by the speed. Something about how I was going to get faster. So that was my beginning, something about my starting and something about my increase as it drops.

\[
\begin{align*}
\dot{v} &= u + at \\
\dot{x} &= ut + \frac{1}{2} at^2 \\
\end{align*}
\]

Figure 5.6: Chris’s oral and written solutions to the Bike task.

Teachers’ interpretations of Chris’s solutions were categorised approximately across Student Thinking, Disciplinary Thinking, or both Student Thinking and Disciplinary Thinking in Table 5.3.
### Table 5.3

*Teachers’ foci when interpreting Chris’s (correct) solutions to the Bike (standard) task*

<table>
<thead>
<tr>
<th>Teachers’ names</th>
<th>Teachers’ foci</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms Jenkins</td>
<td>DT A ST B</td>
</tr>
<tr>
<td>Mr Jackson</td>
<td>DT A ST B</td>
</tr>
<tr>
<td>Ms Johnson</td>
<td>DT A ST B</td>
</tr>
<tr>
<td>Mr Robinson</td>
<td>DT A ST B</td>
</tr>
<tr>
<td>Mr Geraldton</td>
<td>DT A ST B</td>
</tr>
<tr>
<td>Mr Peterson</td>
<td>DT A ST B</td>
</tr>
<tr>
<td>Mr Pierce</td>
<td>DT A ST B</td>
</tr>
<tr>
<td>Ms Chick</td>
<td>DT A ST B</td>
</tr>
<tr>
<td>Ms Jones</td>
<td>DT A ST B</td>
</tr>
<tr>
<td>Mr Sadler</td>
<td>ST A ST B</td>
</tr>
<tr>
<td>Mr Richardson</td>
<td>DT A ST B</td>
</tr>
</tbody>
</table>

Note: DT = Disciplinary Thinking, ST = Student Thinking. Where I coded the responses to be between A & B, I judged the teacher’s attention to be on both DT and ST. Where I coded the responses to be on A, I judged the teacher’s attention to be on both DT and ST but inclined to DT. Where I coded the responses to be on B, I judged the teacher’s attention to be on both DT and ST but inclined to ST.

Table 5.3 shows that all teachers appeared to attend to both Student Thinking and Disciplinary Thinking, when they interpreted Chris’s solutions to the Bike task, with the foci of eight teachers being inclined toward the Student Thinking category. Although all these eight teachers gave the same focus on Chris’s solutions to the motion task or explanation of the formula, the nature or detail of their comments was different. This suggests that the teachers’ PCKs differed. While some teachers gave general attention to Student Thinking, when describing Chris’s problem solving strategy, others attended to Student Thinking, as diagnosing Chris’s solution, for example, Mr Geraldton wrote:

*Chris seems to have a reasonable background knowledge …

Chris seems analytical in his/her approach rather than happy to simply substitute numbers into a formula… The answer is fine…*
Talking yourself through a mental image of the situation (which Chris seems to do) is a good strategy to maintain... Chris’s desire to expect sensibility (and/or familiarity) in the answer is to be highly valued. A lot of students don’t have it or care for it.

Although, the above comments indicate Mr Geraldton overall, focused on both Student Thinking and Disciplinary Thinking, he had an attention to Student Thinking when diagnosing and understanding the process of Chris’s problem solving.

While Ms Jones, Mr Sadler, and Mr Richardson generally attended to both Student Thinking and Disciplinary Thinking (refer to Table 5.3), they placed less emphasis on acknowledging Chris’s appropriate understanding of the principles. Mr Sadler’s written comments on Chris’s solutions exemplify the responses of these teachers:

Starts by thinking about just plugging numbers into equations. Then correctly reasons that horizontal/vertical motion independent. Correctly solves problem, although chooses to use $10 \text{ ms}^{-2}$ for g. Has he forgotten his calculator? Uses vulgar fractions, not decimals. Reasoning is fair, but thoughts seem rather haphazard.

He then clarified the “haphazard” word in his interview, as below:

I think in very fact he is aware you cannot treat the horizontal and ...If he got to explain this to someone else, I am not sure that the other person that [he is] explaining would necessarily grasp the concepts.

For Mr Sadler it was important that Chris obtained the right answer, as he explained in his interview:

I do think he knows what he was doing, because he got the right answer. He does not put the unit but he gets the right answer.

The previous comments indicate that Mr Sadler attended to both Student Thinking and Disciplinary Thinking when he interpreted Chris’s correct solution to the Bike task. Mr Sadler’s beliefs about the learning of motion, and his approach to teaching motion tasks, were in other episode focused on a belief about doing experiments, rather than
any specific teaching and learning strategy for meaningful learning of the theory of linear motion.

**Teachers’ interpretations of Rob’s (incorrect) solutions to standard task:**

As previously explained, each teacher was invited to discuss Rob’s solutions to the standard (Bike) task. Rob’s oral and written solutions are outlined in Figure 5.7:

Rob: I remembered a problem that I had done about dropping an apple from an outstretched hand when driving a car. I considered the initial velocity was the initial velocity of the car, so in this case of the bike that would be 5 m/s. Its final velocity when it hits the ground is zero. It takes 0.45 seconds so that is the time; a is g which is negative, so -10 m/s². Then I used \( v^2 - v_0^2 = 2gh \). I rearranged for h and substituted giving me minus 25 over minus 20, which is 1.25 metres.

![Figure 5.7: Rob’s oral and written solutions to the Bike task.](image)

As Figure 5.7 shows, Rob used rote manipulation and employed the “recursive plug and chug approach” (Tuminaro, 2004) to solve the Bike task, and produced an incorrect solutions. He incorrectly considered the final velocity as zero, indicating some misconceptions of final velocity. Based on the analysis and comparisons of teachers’ foci shown in Appendix D, each teacher interpretations of Rob’s solutions to the Bike task were categorised approximately across Student Thinking, Disciplinary Thinking or both Student Thinking and Disciplinary Thinking in Table 5.4.
### Table 5.4

*Teachers’ foci when interpreting Rob’s (incorrect) solution to the Bike (standard) task*

<table>
<thead>
<tr>
<th>Teachers’ names</th>
<th>Teachers’ foci</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms Jenkins</td>
<td>DT A √ B ET</td>
</tr>
<tr>
<td>Mr Jackson</td>
<td>DT A √ B ET</td>
</tr>
<tr>
<td>Ms Johnson</td>
<td>DT A B ET</td>
</tr>
<tr>
<td>Mr Robinson</td>
<td>DT A √ B ET</td>
</tr>
<tr>
<td>Mr Geraldton</td>
<td>DT A B ET</td>
</tr>
<tr>
<td>Mr Peterson</td>
<td>DT A √ B ET</td>
</tr>
<tr>
<td>Mr Pierce</td>
<td>DT A B ET</td>
</tr>
<tr>
<td>Ms Chick</td>
<td>DT A B ET</td>
</tr>
<tr>
<td>Ms Jones</td>
<td>DT A B ET</td>
</tr>
<tr>
<td>Mr Sadler</td>
<td>DT A B ET</td>
</tr>
<tr>
<td>Mr Richardson</td>
<td>DT A B ET</td>
</tr>
</tbody>
</table>

Note: DT = Disciplinary Thinking, ST = Student Thinking. Where I coded the responses to be between A & B, I judged the teacher’s attention to be on both DT and ST. Where I coded the responses to be on A, I judged the teacher’s attention to be on both DT and ST but inclined to DT. Where I coded the responses to be on B, I judged the teacher’s attention to be on both DT and ST but inclined to ST.

Table 5.4 shows that the perspectives of 10 teachers indicated a focus on both Student Thinking and Disciplinary Thinking, when they interpreted Rob’s solution to the Bike task. The difference in these teachers’ responses was only related to the focus indicated in their comments, which was on either the Student Thinking or the Disciplinary Thinking direction. It needs to be noted that, although some teachers gave the same focus on Rob’s solutions to the motion task or explanation of the formula, the detail of their comments was different.

Mr Peterson’s written and oral comments generally indicated a focus on both Student Thinking and Disciplinary Thinking categories when he interpreted Rob’s solutions (see Table 5.4). He wrote:
Rob’s assumption that the tail light initial velocity is $5 \text{ ms}^{-1}$ is correct but he failed to realize the vector nature of the problem i.e. $d = v_i + 1/2at^2$

His assumption that the final velocity is $0 \text{ ms}^{-1}$ is incorrect. He has taken $g = -10 \text{ ms}^{-1}$ [sic] is fine (though he could equally have used $g = +10 \text{ ms}^{-1}$ [sic])

...He has clearly not understood that the horizontal velocity of the light does not affect the time of fall (in the absence of friction).

These comments show that while Mr Peterson attended to both Student Thinking and Disciplinary Thinking. A close analysis revealed that he was re-presenting Rob’s explanation or performance, rather than interacting with Rob’s explanation when interpreting Rob’s solutions.

Ms Jenkins attended to both Disciplinary Thinking and Student Thinking when she interpreted Rob’s solutions.

It is a good strategy to link a question to a previous question. However the problem Rob has is that he does not fully realize that velocity has a vector nature and that the motion in the vertical and horizontal directions are independent of each other. Rob’s maths would be perfectly appropriate if he realized that it is only the vertical motion that is important, and that in the vertical direction the initial velocity is zero. It also shows that Newton’s first law of motion is not fully understood, as he should realize that in the horizontal direction the tail light would be in a state of constant motion as there is no force acting. The vertical direction is the direction where a force (the force of gravity) acts and causes an acceleration, Therefore it is only the vertical direction that needs to be considered.

The underlined words indicate that Ms Jenkins was interacting predominantly with Rob’s explanation and strategy to solve the Bike task, rather than just re-presenting Rob’s explanation. She also focused on the source of error of Rob’s understanding. This
suggests, while Ms Jenkins’s interpretations of Rob’s solutions fell into both Student Thinking and Disciplinary Thinking categories, her focus inclined toward Student Thinking.

Mr Geraldton’s response fell into both Student Thinking and Disciplinary Thinking categories and his written and oral comments on Rob’s solutions attended to both Student Thinking and Disciplinary Thinking. For example, Mr Geraldton wrote:

There is some interesting logic here; ironically leading to an answer that, whilst incorrect, is feasible.
Rob is confusing horizontal aspects with vertical aspects and they are best treated independently for “projectile motion” problems. Furthermore, he is treating the final vertical velocity of a falling object as zero which is beyond the motion to be analysed.

These comments indicate that Mr Geraldton was involved in both re-presenting and interacting with Rob’s explanations when interpreting Rob’s solutions. For example, he appreciated Rob’s strategy and considered its possibility as a problem solving strategy (see the underlined words) and then he reported Rob’s problem solving strategy.

Ms Chick’s response fell into both Student Thinking and Disciplinary Thinking categories inclined towards Disciplinary Thinking, when she interpreted Rob’s solutions (see Table 5.4). Ms Chick’s written comments to Rob’s solutions exemplified this focus:

He has a logical approach to the task. His strategy is to write down all the information he has and then decide which of the kinematic equations to use. This is a good strategy and is one I use to solve these problems.
He does not understand that he must separate out vertical motion from horizontal motion... As the lamp will be falling vertically, the initial vertical velocity should be used.
Rob also does not understand when the final velocity is measured. The final velocity should be measured just before the lamp hits the ground. Rob has interpreted ‘final velocity’ to mean once the lamp has hit the ground and come to rest... he
did use the correct kinematics equation for the information he thought he had. Rob also used the correct mathematical methods to solve this equation coming up with a mathematically correct answer.

Ms Chick compared Rob’s approach with her own approach to solve the task (see underlined words), which is an attention to Disciplinary Thinking. While Rob obtained an incorrect answer, Ms Chick appreciated Rob’s strategy (see underlined phrases). It also seems that Ms Chick attended to Rob’s thinking and the method Rob used in his strategy (see underlined phrases). Overall these comments indicate a dual attention to both Disciplinary Thinking and Student Thinking.

As shown in Table 5.4, Mr Sadler’s interpretation fell into the Disciplinary Thinking category and his written comments exemplified this focus:

- Rob doesn’t realize that horizontal & vertical motion [are] independent.
- Treats 5 ms⁻¹ as a vertical vel – wrong.
- Says that 0 ms⁻¹ is final vertical velocity. Not true – needs to talk about vertical velocity as it hits ground.
- Uses horizontal velocity but vertical acceleration.

These written comments indicate that he just re-presented the content used in, and the process of, problem solving, rather than interacting with the student’s formulation and explanation. His emphasis fell into only Disciplinary Thinking.

In order to distinguish possible similarities and differences that might be discerned in teachers’ interpretations of Chris and Rob’s solutions to the Bike task, these interpretations are compared in Table 5.5.

Table 5.5 shows that the focus of individual teacher interpretation varied according to the type of task and student solutions. The table also shows that while most teachers’ interpretations indicated a focus on both Student Thinking and Disciplinary Thinking, some inclined either toward Student Thinking and others toward Disciplinary Thinking, when they interpreted Rob’s and Chris’s solutions.

Table 5.5 also shows that there was a general pattern in teachers’ interpretations in which all teachers except four (Ms Jenkins, Mr Geraldton, Mr Pierce, Ms Jones) shifted
their foci from an Student Thinking toward a Disciplinary Thinking category, when they interpreted Chris’s correct and Rob’s incorrect solutions. This suggests that the incorrect solutions might have (not surprisingly) prompted a focus on the Disciplinary Thinking category when the teachers interpreted Rob’s solutions to the task.

### Table 5.5
Comparison of teachers’ foci when interpreting Chris’s (correct) and Rob’s (incorrect) solutions to the Bike (standard) task

<table>
<thead>
<tr>
<th>Teachers’ names</th>
<th>Teachers’ foci on Chris’s correct solution</th>
<th>Teachers’ foci on Rob’s incorrect solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms Jenkins</td>
<td>DT: A B ST A B DT</td>
<td>DT: A B ST A B DT</td>
</tr>
<tr>
<td>Mr Jackson</td>
<td>DT: A B ST A B DT</td>
<td>DT: A B ST A B DT</td>
</tr>
<tr>
<td>Ms Johnson</td>
<td>DT: A B ST A B DT</td>
<td>DT: A B ST A B DT</td>
</tr>
<tr>
<td>Mr Robinson</td>
<td>DT: A B ST A B DT</td>
<td>DT: A B ST A B DT</td>
</tr>
<tr>
<td>Mr Geraldton</td>
<td>DT: A B ST A B DT</td>
<td>DT: A B ST A B DT</td>
</tr>
<tr>
<td>Mr Peterson</td>
<td>DT: A B ST A B DT</td>
<td>DT: A B ST A B DT</td>
</tr>
<tr>
<td>Mr Pierce</td>
<td>DT: A B ST A B DT</td>
<td>DT: A B ST A B DT</td>
</tr>
<tr>
<td>Ms Chick</td>
<td>DT: A B ST A B DT</td>
<td>DT: A B ST A B DT</td>
</tr>
<tr>
<td>Ms Jones</td>
<td>DT: A B ST A B DT</td>
<td>DT: A B ST A B DT</td>
</tr>
<tr>
<td>Mr Sadler</td>
<td>DT: A B ST A B DT</td>
<td>DT: A B ST A B DT</td>
</tr>
<tr>
<td>Mr Richardson</td>
<td>DT: A B ST A B DT</td>
<td>DT: A B ST A B DT</td>
</tr>
</tbody>
</table>

Note: DT= Disciplinary Thinking, ST= Student Thinking. Where I coded the responses to be between A & B, I judged the teacher’s attention to be on both DT and ST. Where I coded the responses to be on A, I judged the teacher’s attention to be on both DT and ST but inclined to DT. Where I coded the responses to be on B, I judged the teacher’s attention to be on both DT and ST but inclined to ST.

In order to address the research questions, it also is important to explore the ways that teachers respond to a student’s incorrect solution for the non-standard motion task, explained below.

*Teachers’ interpretations of Karl’s (incorrect) solution to non-standard task*

Each teacher was asked to interpret student solutions – Karl’s and Mike’s – to the non-standard (Shoved Block) task in the interview. Most teachers did not comment on
Chapter 5: Results

Mike’s solutions. This may be due to the fact that Mike’s response to the Shoved Block task was brief. The student’s discussion about Shoved Block task are in Figure 5.8.

<table>
<thead>
<tr>
<th>Shoved Block Question and students’ discussion of the question:</th>
</tr>
</thead>
<tbody>
<tr>
<td>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? (see Figure 4.3).</td>
</tr>
</tbody>
</table>

A heavier and a lighter block slide to a halt on a table.  
(Adapted from Sherin, 2001, p. 488)

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 5.8: Shoved Block task and two students’ discussion (Karl and Mike) of the task.

As shown in Figure 5.8 Karl provided an incorrect answer which eventually leads him to invent a new formula that could not be found in any physics book.

Based on the analysis and comparisons of teachers’ comments and foci shown in Appendix D, each teacher interpretations of Karl’s solutions to the Shoved Block task
were categorised approximately across Student Thinking, Disciplinary Thinking or both St and Disciplinary Thinking in Table 5.6.

Table 5.6
Teachers’ foci, when interpreting Karl’s (incorrect) solution to the Shoved Block (non-standard) task

<table>
<thead>
<tr>
<th>Teachers’ names</th>
<th>Teachers’ foci</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms Jenkins</td>
<td>DT A</td>
</tr>
<tr>
<td></td>
<td>ST B</td>
</tr>
<tr>
<td>Mr Jackson</td>
<td>DT A</td>
</tr>
<tr>
<td></td>
<td>ST B</td>
</tr>
<tr>
<td>Ms Johnson</td>
<td>DT A</td>
</tr>
<tr>
<td></td>
<td>ST B</td>
</tr>
<tr>
<td>Mr Robinson</td>
<td>DT A</td>
</tr>
<tr>
<td></td>
<td>ST B</td>
</tr>
<tr>
<td>Mr Geraldton</td>
<td>DT A</td>
</tr>
<tr>
<td></td>
<td>ST B</td>
</tr>
<tr>
<td>Mr Peterson</td>
<td>DT A</td>
</tr>
<tr>
<td></td>
<td>ST B</td>
</tr>
<tr>
<td>Mr Pierce</td>
<td>DT A</td>
</tr>
<tr>
<td></td>
<td>ST B</td>
</tr>
<tr>
<td>Ms Chick</td>
<td>DT A</td>
</tr>
<tr>
<td></td>
<td>ST B</td>
</tr>
<tr>
<td>Ms Jones</td>
<td>DT A</td>
</tr>
<tr>
<td></td>
<td>ST B</td>
</tr>
<tr>
<td>Mr Sadler</td>
<td>DT A</td>
</tr>
<tr>
<td></td>
<td>ST B</td>
</tr>
<tr>
<td>Mr Richardson</td>
<td>DT A</td>
</tr>
<tr>
<td></td>
<td>ST B</td>
</tr>
</tbody>
</table>

Note: DT= Disciplinary Thinking, ST= Student Thinking. Where I coded the responses to be between A & B, I judged the teacher’s attention to be on both DT and ST. Where I coded the responses to be on A, I judged the teacher’s attention to be on both DT and ST but inclined to DT. Where I coded the responses to be on B, I judged the teacher’s attention to be on both DT and ST but inclined to ST.

Table 5.6 shows that the teachers’ perspectives were distributed in three zones: Disciplinary Thinking, both Student Thinking and Disciplinary Thinking, and Student Thinking. Six teachers attended to either of Disciplinary Thinking or Student Thinking. Given the task is non-standard, that the formulation is not identical with the standard mathematical equation and the teachers had less experience teaching this kind of task, and so likely had less experience interacting with the kinds of difficulties that students might have in solving the task. It is not surprising they were less inclined to attend to both Disciplinary Thinking and Student Thinking in their interpretation of student solutions.
Ms Chick was a teacher who attended to Student Thinking, when she interpreted Karl’s solutions to the Shoved Block task:

...he has a perception of what happens because he’s seen things in his life happen that heavier objects take longer to come to a stop. So he’s seen a big truck going down a road and he’s gone a big truck is heavy ...he’s travelled on a train that is something big and heavy ...whereas in a car it’s a smaller thing and he sees that it takes a shorter distance to come to a stop. So he’s got an idea from his experiences that he calls common sense that he’s trying to make the situation fit, he hasn’t made that link between what the concepts say and what his manipulation of numbers is saying.

The above excerpt of Ms Chick’s interview indicates an interaction with Karl’s explanation and formulation in order to justify Karl’s explanations and thoughts. Therefore, Ms Chick’s focus inclined to Student Thinking.

Based on Table 5.6, Mr Richardson was an example of a teacher whose interpretations fell into the Disciplinary Thinking category. His statement about Karl’s solutions (in interview) elaborates this focus:

That’s tied in with this earlier bit where he’s saying the larger the weight the less the coefficient of friction would be, that doesn’t seem to make sense, because the heavier the object the harder it is to slide and it’s my understanding that the coefficient of friction is a degree of how hard it is the two surfaces could slide over one another, so I think that’s an error,....

This comment indicates a strong attention to the content used and the process of problem solving, and thus was categorised Disciplinary Thinking.

Mr Peterson’s interpretation of Karl’s solutions fell into the zone of both Student Thinking and Disciplinary Thinking but inclined toward Disciplinary Thinking. Two sections from his interview transcripts help to explain this categorisation. For example, he stated in his interview:
... there’s some wrong material and some correct material... So I still say the heavier object will take longest to stop and the lighter one is wrong, just as a matter of common sense, well it’s wrong. ...The only thing that could be the coefficient of friction is not constant. Now it’s not the coefficient of friction that is not constant ‘cause it is constant, what is different is the friction force, so he’s confusing coefficient of friction with actual friction force. But then I think he’s correct here I guess where he’s saying with the larger weight, the less the coefficient of friction would be. So that’s wrong also.

The above quote suggests that Mr Peterson attention to the correctness or incorrectness of Karl’s performance indicated a focus on Disciplinary Thinking.

However, he also stated in his interview:

*Karl’s second attempt is a much better explanation of what this equation means. Yeah. ‘Cause he is explaining the larger the normal force the smaller this component will be, so if it gets to be really heavy the only thing you get left is $\mu_1$. So this is a good explanation of his equation, his equation is not however correct but it’s a good explanation of the equation he has devised.*

This indicates that Mr Peterson appreciated Karl’s understanding of mathematical modelling and gave a focus on the Student Thinking category. However, as noted earlier, Mr Peterson’s overall response fell into the category of both Student Thinking and Disciplinary Thinking but inclined towards Disciplinary Thinking.

Table 5.7 illustrates the foci of teachers’ interpretations of two incorrect solutions from Karl and Rob, in order to provide/distinguish a clear picture of teacher perspectives or beliefs. Table 5.7 shows that, although both Rob and Karl had misconceptions and both were unable to solve their respective tasks correctly (i.e. Bike and Shoved Block), many teachers attended to both Student Thinking and Disciplinary Thinking, when interpreting Rob’s solutions. This was not the case with the teachers’ interpretations of Karl’s solutions. Only four teachers (Mr Robinson, Mr Geraldton, Mr Peterson, Mr Pierce) remained in both Student Thinking and Disciplinary Thinking, but
the rest shifted towards either Disciplinary Thinking or Student Thinking, when they interpreted Karl’s incorrect solutions to the Shoved Block task. This suggests that the type of tasks themselves influenced the teachers’ approaches to interpreting student solutions, rather than students’ correct or incorrect solutions. This reflected teachers’ distinctive PCKs. This suggests a need to investigate teachers’ interpretations with respect to the type of task, as explained in section 5.4.2.

Table 5.7
Comparison of teachers’ foci when interpreting incorrect solution to the Bike (standard) and Shoved Block (non-standard) tasks

<table>
<thead>
<tr>
<th>Teachers’ names</th>
<th>Teachers’ foci on Rob’s (incorrect) solution to the Bike task</th>
<th>Teachers’ foci on Karl’s (incorrect) solution to the Shoved Block task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms Jenkins</td>
<td>DT: A, B ST:</td>
<td>DT: A, B ST:</td>
</tr>
<tr>
<td>Mr Jackson</td>
<td>DT: A</td>
<td>DT: A, B ST:</td>
</tr>
<tr>
<td>Ms Johnson</td>
<td>DT: A, B ST:</td>
<td>DT: A, B ST:</td>
</tr>
<tr>
<td>Mr Robinson</td>
<td>DT: A, B ST:</td>
<td>DT: A, B ST:</td>
</tr>
<tr>
<td>Mr Geraldton</td>
<td>DT: A, B ST:</td>
<td>DT: A, B ST:</td>
</tr>
<tr>
<td>Mr Peterson</td>
<td>DT: A, B ST:</td>
<td>DT: A, B ST:</td>
</tr>
<tr>
<td>Mr Pierce</td>
<td>DT: A, B ST:</td>
<td>DT: A, B ST:</td>
</tr>
<tr>
<td>Ms Chick</td>
<td>DT: A, B ST:</td>
<td>DT: A, B ST:</td>
</tr>
<tr>
<td>Ms Jones</td>
<td>DT: A, B ST:</td>
<td>DT: A, B ST:</td>
</tr>
<tr>
<td>Mr Sadler</td>
<td>DT: A, B ST:</td>
<td>DT: A, B ST:</td>
</tr>
<tr>
<td>Mr Richardson</td>
<td>DT: A, B ST:</td>
<td>DT: A, B ST:</td>
</tr>
</tbody>
</table>

Note: DT = Disciplinary Thinking, ST = Student Thinking. Where I coded the responses to be between A & B, I judged the teacher’s attention to be on both DT and ST. Where I coded the responses to be on A, I judged the teacher’s attention to be on both DT and ST but inclined to DT. Where I coded the responses to be on B, I judged the teacher’s attention to be on both DT and ST but inclined to ST.

5.4.2 Categorization of teachers’ interpretations with respect to type of task (standard/non-standard)

Each teacher’s focus with respect to their interpretations of 5 student solutions to the Bike (standard) and Shoved Block (non-standard) tasks, was coded and summarised in
Appendix D. Judgments about the teachers’ overall focus across the solutions of three students (Rob, Chris, and Sue) to the standard task and of two student (Karl and Mike) to the non-standard task were made, and then approximately categorised in Table 5.8.

Table 5.8
Comparison of teachers’ overall foci when interpreting students’ solutions to the Bike (standard) and Shoved Block (non-standard) tasks

<table>
<thead>
<tr>
<th>Teachers’ names</th>
<th>Teachers’ foci on students’ solutions for the Bike task</th>
<th>Teachers’ foci on students’ solutions for the Shoved Block task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms Jenkins</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
</tr>
<tr>
<td>Mr Jackson</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
</tr>
<tr>
<td>Ms Johnson</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
</tr>
<tr>
<td>Mr Robinson</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
</tr>
<tr>
<td>Mr Geraldton</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
</tr>
<tr>
<td>Mr Peterson</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
</tr>
<tr>
<td>Mr Pierce</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
</tr>
<tr>
<td>Ms Chick</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
</tr>
<tr>
<td>Ms Jones</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
</tr>
<tr>
<td>Mr Sadler</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
</tr>
<tr>
<td>Mr Richardson</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
<td>DT A ✔️ B ✔️ ST ✔️</td>
</tr>
</tbody>
</table>

Note: DT= Disciplinary Thinking, ST= Student Thinking. Where I coded the responses to be between A & B, I judged the teacher’s attention to be on both DT and ST. Where I coded the responses to be on A, I judged the teacher’s attention to be on both DT and ST but inclined to DT. Where I coded the responses to be on B, I judged the teacher’s attention to be on both DT and ST but inclined to ST.

Table 5.8 shows that all teachers’ responses indicate dual attention to both Student Thinking and Disciplinary Thinking, when they interpreted students’ solutions to the standard (Bike) task. The table also shows a shift toward Disciplinary Thinking in seven teachers’ responses, when they interpreted students’ solutions to the non-standard task. This perhaps is not surprising, as the nature of the task likely causes or forces teachers to think more deeply about the content, as they interpreted the student solutions. In addition, as noted earlier, they were less experienced with student difficulties with this
kind of task, as it was non-standard, which may also contribute to their attention shifting away from Student Thinking when they interpreted the student solutions.

Summary

Focus on students’ solutions (correct and incorrect)
A comparison of teachers’ interpretations of Chris’s correct and Rob’s incorrect solutions indicated that their attention shifted from both Student Thinking and Disciplinary Thinking but inclined to Student Thinking – for Chris’s correct solutions – and to both Student Thinking and Disciplinary Thinking but inclined to the Disciplinary Thinking – for Rob’s incorrect solutions. In general, the teachers’ interpretations of Chris’s correct, and Rob’s and Karl’s incorrect solutions to the standard and non-standard tasks respectively shifted towards the Disciplinary Thinking direction. This is unsurprising; it is understandable that the teachers felt no need to comment on Chris’s understanding beyond the observation that he was correct, whereas Rob’s and Karl’s solutions indicated their lack of understanding or misconceptions concerning the formula and solving motion tasks, thus leading teachers to incline their focus more in the Disciplinary Thinking direction.

Focus on type of task (standard and non-standard)
With respect to comparison of teachers’ interpretations of the students’ solutions to the standard and non-standard task, these varied from both Student Thinking and Disciplinary Thinking to Student Thinking or Disciplinary Thinking. It is important to recognise that the physics teachers needed to have richer content knowledge in the motion topic to solve the non-standard task (Shoved Block) than was required for the standard tasks (Bike and Glider). As the theoretical perspective outlined in Chapter 3 suggested, it is likely that the teachers’ interpretations of students’ solutions to the non-standard task were related to their level of content knowledge in the area of motion topic (Sanders, Borko & Lockard, 1993). This relationship will be discussed in Chapter 6.

5.4.3 Categorization of teachers’ interpretations of the students’ explanations of the formula:  \( v = v_0 + at \)

Each teacher was asked to discuss the explanations of the formula \( v = v_0 + at \) given by three hypothetical students, Mary, Michelle and Simon (Figures 5.9 – 5.11):
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Mary: It [above equation, \( v = v_0 + at \)] means a starting bit plus a movement bit [writes “velocity = starting bit + movement bit”]. And the starting bit [circles “starting bit”] was the base was zero speed and this one [circles “movement bit”] was the movement caused by g.

Figure 5.9: Mary’s explanation about the formula \( v = v_0 + at \).

Michelle: Well yeah it is obvious because, well velocity will equal to \( v_0 \) if it’s not being disturbed. But if it’s being acc— If there’s a f—acceleration action on it, then uh—and that’s constant, you know then velocity will be decreasing as time goes on. Or increasing, whatever it works, I mean whichever it does. So, it’s like whatever it is and then plus a correction on the acceleration. So yeah it makes sense. It’s obvious, yes it is.

Figure 5.10: Michelle’s explanation about the formula \( v = v_0 + at \).

Simon: What’s obvious to me is that you have the final velocity is obviously going to be equal to the initial velocity plus however much, however faster it gets. That’s what’s obvious to me. What’s not necessarily positively obvious is that the amount, the amount that it gets faster is the acceleration times the time.

Figure 5.11: Simon’s explanation about the formula \( v = v_0 + at \).

In order to address the first research question, it is important to explore the general patterns arising from the teachers’ interpretations of the students’ explanations of the formula. The teacher interpretations of the students’ explanations of the formula \( v = v_0 + at \) with respect to the categories Student Thinking and Disciplinary Thinking are outlined in 5.9.
Table 5.9

**Teachers’ overall foci when interpreting students’ explanations of the formula**

\[ v = v_0 + at \]

<table>
<thead>
<tr>
<th>Teachers’ names</th>
<th>Teachers’ foci</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms Jenkins</td>
<td>DT: A, ST: B</td>
</tr>
<tr>
<td>Mr Jackson</td>
<td>DT: A, ST: B</td>
</tr>
<tr>
<td>Ms Johnson</td>
<td>DT: A, ST: B</td>
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<td>Mr Robinson</td>
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</tr>
<tr>
<td>Mr Pierce</td>
<td>DT: A, ST: B</td>
</tr>
<tr>
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<td>DT: A, ST: B</td>
</tr>
<tr>
<td>Ms Jones</td>
<td>DT: A, ST: B</td>
</tr>
<tr>
<td>Mr Sadler</td>
<td>DT: A, ST: B</td>
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<tr>
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Note: DT = Disciplinary Thinking, ST = Student Thinking. Where I coded the responses to be between A & B, I judged the teacher’s attention to be on both DT and ST. Where I coded the responses to be on A, I judged the teacher’s attention to be on both DT and ST but inclined to DT. Where I coded the responses to be on B, I judged the teacher’s attention to be on both DT and ST but inclined to ST.

Table 5.9 shows that most teachers’ responses indicated a focus on both Student Thinking and Disciplinary Thinking, when they interpreted the students’ explanations of the formula \[ v = v_0 + at \], which is consistent with teacher interpretations of student solutions to the Bike task. However, the responses of most of these teachers inclined toward the Student Thinking category.

Ms Chick’s comments indicated dual attention to both Student Thinking and Disciplinary Thinking, when she interpreted Michelle’s explanation of the formula \[ v = v_0 + at \]:

*She can repeat what she has been told but isn’t showing much understanding. She gets the idea that acceleration will change*
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the velocity but either doesn’t have an understanding of the concept or is very bad at expressing her understanding. She knows enough to use the equation correctly, but would probably have difficulty using the equation in explanation questions

The underlined words and phrase indicate Ms Chick’s dual attention to both Student Thinking and Disciplinary Thinking. Ms Chick also stated:

Simon understands how objects speed up, but doesn’t understand how acceleration can make an object slow down. This appears to be a problem with his understanding of the concept of acceleration not his understanding of the equation. He clearly states that the equation has two parts, the initial velocity and the change in velocity caused by an acceleration.

This comment shows dual attention to both Student Thinking and Disciplinary Thinking, inclined to Disciplinary Thinking. Although Ms Chick placed emphasis on Simon’s understanding, she was just re-presenting Simon’s explanation of his difficulty in understanding acceleration, rather than interacting with Simon’s explanation and thought in order to explore Simon’s difficulty.

Mr Sadler attended overall to Disciplinary Thinking, when interpreting three students’ explanations of the formula (see Table 5.9). His written comments on Michelle are:

Again, seems to have the basic idea, but cannot explain it well. I am not sure what she means by the ‘correction on the acceleration’. She gets the idea of the acceleration causing the velocity to increase or decrease.

Mr Sadler only re-presents Michelle’s words, but does not interact with Michelle’s explanation to diagnose her difficulty in understanding the formula. His interpretation of Simon’s explanation is as follows:

Simon explains the first part well. He says that it is not obvious to him how much faster the object gets. But then he goes on to say that it increases velocity by acceleration times time, which is correct. I think he understands the idea better than he realizes... he thinks that he’s not understanding things properly... because
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It’s simple he doesn’t need to understand … he doesn’t need to try and draw any more out of the equation...

This comment further indicates an attention to Disciplinary Thinking (see the underlined words) in comparing Simon’s understanding with other students (Mary and Michelle):

The best one[student] would be Simon seems to … Simon understands it, I think Simon understands it the most, yes … So I think he doubts his own understanding, he expects it to be more difficult than it really is, but I do think Simon understands it… what Simon says is probably similar to the way I would teach it

It appears that Mr Sadler uses an approach to teach the formula which is similar to his understanding of Simon’s explanation of the formula. This may cause Mr Sadler to suppose Simon understood the formula. I interpret Mr Sadler’s comments as having an attention to Disciplinary Thinking.

5.5 Teachers’ feedback on student solutions

As previously mentioned, each teacher was requested to provide feedback on students’ solutions for the standard (Bike) and non-standard (Shoved Block) tasks, as well as on students’ explanations of the formula: \( v = v_0 + at \). These teachers’ comments were analysed across the Disciplinary Thinking and Student Thinking categories. An in-depth analysis of each teacher’s written feedback on individual student solutions established a clearer picture or pattern of the teacher’s focus. Each teacher’s focus was identified from both his/her written comments and the interview excerpts. As explained in Chapter 4, some teachers’ responses were more extensive and comprehensive than others. Through the initial coding and analysis, each teacher’s comments were reduced, coded, and then summarised in Appendix D.

The foci of each teacher’s response that are identified and discussed are illustrated by some underlined excerpts (which indicate the researcher’s emphasis) on teachers written and oral comments in this chapter. As explained in Chapter 4, section 4.4.3 step 7 of analysis, these excerpts can be a word, phrase, sentence, or a paragraph or whole
teacher comments to a student. It was possible to give a label to a teacher by looking across all teacher comments.

Comparative analyses were conducted to identify the patterns or relationships between the teacher’s feedback across variations of the students’ solutions, and the type of motion tasks. In order to address the second research question, concerned with teacher feedback, it was important to explore the differences and similarities between the teachers’ feedback with respect to types of student solutions; that is, the students’ correct or incorrect solutions (see section 5.5.1), and types of tasks, standard and non-standard (see section 5.5.2). Finally, teachers’ feedback on three students’ explanations/understandings of the equation \( v = v_0 + at \) will also be explained (see section 5.5.3).

The teachers’ feedback are categorised approximately across Student Thinking and Disciplinary Thinking in the tables throughout section 5.5. These categorization explore teachers’ feedback on only two student (Chris, Rob) solutions to the Bike task, teachers’ general foci on three student (Mary Michelle, Simon), and teachers’ feedback on only one student (Karl) solutions to Shoved Block task. Teachers’ feedback on Chris’s solutions were categorised approximately across Student Thinking and Disciplinary Thinking in Table 5.10.

### 5.5.1 Categorization of teachers’ feedback with respect to the student solutions

The second research question concerned an exploration of the different ways teachers provide feedback on a student’s correct and incorrect solutions to the motion tasks. As previously explained Rob used rote manipulation and produced the incorrect solutions to the Bike task. Chris’s solutions to the Bike task indicate an appropriate understanding of the formulae in the context of the question. Karl’s solutions to the Shoved Block task indicates an incorrect understanding of the task, which eventually led him to attempt to invent a new mathematical model.

In this section, the different foci of the teachers’ feedback to the solutions of Chris, Rob, and Karl are reported. The comparison of the teachers’ foci is elaborated with respect to their feedback to Chris’s correct and Rob’s incorrect solutions to the standard task. Also the comparison of the teachers’ perspectives with regards to their feedback to Rob and Karl’s incorrect solutions for the non-standard (Shoved Block) task is reported. Based on the description of the Student Thinking and Disciplinary Thinking categories,
detailed in Chapter 4 and Appendix C, the comments that fell in the Student Thinking
category comprised using the current student solutions to guide, motivate, and/or help
improve the students’ thinking, explanation, and decisions to use appropriate strategies.
In fact, these teachers carefully went through each step of the strategies in the solutions
produced by a student. For example, in their feedback teachers indicated they would ask
different questions, and encourage student to review his/her work, so they could
understand his/her thoughts. These teachers indicated that they might invite student to
solve more examples and do some experiments in a similar context, when constructing
feedback.

Some examples of teachers’ feedback that attended to Disciplinary Thinking were:
using multiple examples of similar motion tasks, and using experiments and DVDs.
Moreover, teachers sometimes introduced new content or gave multiple examples (in
the new context), when providing feedback on student solutions. Using an example in a
new context may involve new content or the use of a new equation.

Some teachers’ written and verbal comments that exemplify the Student Thinking,
Disciplinary Thinking, or both Student Thinking and Disciplinary Thinking focus are
explained throughout this section.

**Teachers’ feedback to Chris’s (correct) solution**
Analysis of the teachers’ written feedback to student solutions revealed the teachers’
thinking, intentions or beliefs. Each teacher feedback on Chris’s solutions to the Bike
task were categorised approximately across Student Thinking, Disciplinary Thinking or
both Student Thinking and Disciplinary Thinking in Table 5.10.

Table 5.10 shows that six teachers’ feedback fell into both Student Thinking and
Disciplinary Thinking, and few teachers gave focus on only Disciplinary Thinking or
Student Thinking. Mr Richardson did not provide sufficient comment, as he just stated
“well done” when providing feedback on Chris’s solutions. Thus, his feedback was not
classified. Some excerpts from teachers’ written and verbal responses are explained in
the next page.
Table 5.10
Teachers’ foci when providing feedback on Chris’s (correct) solutions to the Bike (standard) task

<table>
<thead>
<tr>
<th>Teachers’ names</th>
<th>Teachers’ foci</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms Jenkins</td>
<td>DT A</td>
</tr>
<tr>
<td>Mr Jackson</td>
<td>DT A</td>
</tr>
<tr>
<td>Ms Johnson</td>
<td>DT A</td>
</tr>
<tr>
<td>Mr Robinson</td>
<td>DT A</td>
</tr>
<tr>
<td>Mr Geraldton</td>
<td>DT A</td>
</tr>
<tr>
<td>Mr Peterson</td>
<td>DT A</td>
</tr>
<tr>
<td>Mr Pierce</td>
<td>ST B</td>
</tr>
<tr>
<td>Ms Chick</td>
<td>ST B</td>
</tr>
<tr>
<td>Ms Jones</td>
<td>ST B</td>
</tr>
<tr>
<td>Mr Sadler</td>
<td>ST B</td>
</tr>
<tr>
<td>Mr Richardson</td>
<td>DT A</td>
</tr>
</tbody>
</table>

Note: DT = Disciplinary Thinking, ST = Student Thinking. Where I coded the responses to be between A & B, I judged the teacher’s attention to be on both DT and ST. Where I coded the responses to be on A, I judged the teacher’s attention to be on both DT and ST but inclined to DT. Where I coded the responses to be on B, I judged the teacher’s attention to be on both DT and ST but inclined to ST.

Ms Chick believed that Chris’s oral expression needed to be improved, as this is evident from her written comments:

*Spend time helping him verbalize his answers; he showed excellent understanding of the concepts but just needs help to put it into word...*

Ms Chick added in her interview as follows:

*And I get the impression here that he’s repeating without showing any understanding. She needs to apply it and she needs practice applying it, and whether that’s written down initially or*
initially talking her way through it through group work, she needs practice.

Ms Chick highlighted Chris’s difficulty in verbalizing the answer, which other teachers did not specifically point out. Ms Chick overall attended to both Student Thinking and Disciplinary Thinking, when providing feedback to Chris’s solutions, which is consistent with her interpretation of Chris’s solutions, which attended to both Student Thinking and Disciplinary Thinking.

In addition, Ms Johnson’s feedback to Chris’s solutions fell into both Student Thinking and Disciplinary Thinking categories, as her written comments illustrate:

Mostly I would suggest Chris starts by thinking and imagining the object rather than starting with I need some formulas!
So I would use a diagram and think aloud with him about what is actually happening first, then get him to list the relevant data before selecting an equation. I would also get him then to decide if his answer was reasonable for the problem described (value and accuracy).

Ms Johnson worked on Chris’s solutions to lead him to understand and think about the process of solving the task (see the underlined words). Ms Johnson attended to both Student Thinking and Disciplinary Thinking when constructing feedback to Chris, which is similar to the perspective she had used when interpreting Chris’s solution. As was the case with Ms Chick, Ms Johnson’s focus was consistent with what might have been predicted from the theoretical perspective of the thesis.

In a similar vein, Mr Geraldton wrote:

To me, Chris needs to do more problems (and with variety) so that he/she gains confidence in the formulae.

Typically, recommendations for using a variety of examples (see the underlined words) or experiments that were justified in terms of increasing a student’s confidence were interpreted (by researcher) as a Disciplinary Thinking focus. However, Mr Geraldton added some statements (in the questionnaire), which indicate a dual attention to Student Thinking and Disciplinary Thinking, with an inclination toward Student Thinking (see the underlined words).
Again, he/she needs to be confirmed in his/her acquired understanding. Talking yourself through a mental image of the situation (which Chris seems to do) is a good strategy to maintain. Using a calculator should also help and perhaps there needs to be an encouragement to write less. Chris’s desire to expect sensibility (and/or familiarity) in the answer is to be highly valued. A lot of students don’t have it or care for it.

Mr Geraldton’s feedback includes working with, and appreciating, Chris’s solutions. He also encouraged Chris to use his imagination and write less. These comments show that he inclined towards Student Thinking when providing feedback to Chris’s solutions to the Bike task. This is similar to the perspective he had used when interpreting Chris’s solutions to the Bike task.

A small group of teachers’ comments fell into the Disciplinary Thinking category when they provided feedback to Chris’s solution. Some excerpts from teachers’ written and verbal responses are outlined below.

Mr Pierce was grouped in the Disciplinary Thinking category when providing feedback to Chris’s solution. He wrote,

... I would suggest, once Chris establishes this question is about a falling object, he should list the data he has available as well as assumptions, E.g. \( g = 10 \text{m/s}^2 \), \( v_0 = 0 \), and the equations available. Then he can select the appropriate equation based on the data available.

As this comment shows, Mr Pierce emphasized the algorithms used in task, and the process of problem solving, which suggests a Disciplinary Thinking focus. When interpreting Chris’s solution, his attention fell into both the Student Thinking and the Disciplinary Thinking categories. This was interesting as, from the perspective of the theoretical framework for this thesis discussed in Chapter 3, it might have been expected that his feedback would also attend to both Student Thinking and Disciplinary Thinking, which is consistent with the focus of his interpretation of Chris’s solution.

Mr Jackson also attended to both Student Thinking and Disciplinary Thinking, when providing feedback on Chris’s solution. His written comments exemplify this focus:
Work on visualizing situations would be good.
Using a calculator should be second nature!
As with Rob, Chris also need to get involved doing practical work with balls dropping and being projected would help this aspect.
The use of videos/DVD or applets to help develop the concepts of the independent motion is required.
Plain old hard work and repetition through multiple examples/problems is paramount.

These comments show that Mr Jackson’s priority in constructing feedback is building upon motion experiences, and visualizing the situations. It seems that Chris’s performance probably influenced the last statement of Mr Jackson’s comments. This comment is consistent with a traditional teaching emphasis and indicates a focus on Disciplinary Thinking. Overall, Mr Jackson’s feedback to Chris’s solutions indicates a focus on both Student Thinking and Disciplinary Thinking, and this is consistent with his interpretation of Chris’s solution. In addition, he used the same written feedback on the solutions of other students (Sue and Rob) to the Bike task, which was a unique case in this research. This is different to what might have been embedded in the theoretical perspective of the thesis. It might have been expected that his feedback would be different to different student solutions, views, and needs. That is, he would show that he could respond differently to different student constructions. This did not appear to be the case and this reflects a poor level of integrated pedagogical teacher knowledge.

Teachers’ feedback to Rob’s (incorrect) solution to the standard task
Through analysis of the teachers’ feedback on Rob’s incorrect solutions to the standard (Bike) task, the teachers’ foci were explored (see Appendix D). Each teacher feedback on Rob’s solutions to the Bike task were categorised approximately across Student Thinking, Disciplinary Thinking or both Student Thinking and Disciplinary Thinking in Table 5.11.
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Table 5.11
Teachers’ foci, when providing feedback on Rob’s (incorrect) solution to the Bike (standard) task

<table>
<thead>
<tr>
<th>Teachers’ names</th>
<th>Teachers’ foci</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms Jenkins</td>
<td>DT A B ST</td>
</tr>
<tr>
<td>Mr Jackson</td>
<td>DT A B ST</td>
</tr>
<tr>
<td>Ms Johnson</td>
<td>DT A B ST</td>
</tr>
<tr>
<td>Mr Robinson</td>
<td>DT A B ST</td>
</tr>
<tr>
<td>Mr Geraldton</td>
<td>DT A B ST</td>
</tr>
<tr>
<td>Mr Peterson</td>
<td>DT A B ST</td>
</tr>
<tr>
<td>Mr Pierce</td>
<td>DT A B ST</td>
</tr>
<tr>
<td>Ms Chick</td>
<td>DT A B ST</td>
</tr>
<tr>
<td>Ms Jones</td>
<td>DT A B ST</td>
</tr>
<tr>
<td>Mr Sadler</td>
<td>DT A B ST</td>
</tr>
<tr>
<td>Mr Richardson</td>
<td>DT A B ST</td>
</tr>
</tbody>
</table>

Note: DT= Disciplinary Thinking, ST= Student Thinking. Where I coded the responses to be between A & B, I judged the teacher’s attention to be on both DT and ST. Where I coded the responses to be on A, I judged the teacher’s attention to be on both DT and ST but inclined to DT. Where I coded the responses to be on B, I judged the teacher’s attention to be on both DT and ST but inclined to ST.

The general pattern identified by looking at Table 5.11 is, while majority of teachers’ feedback on Rob’s solutions have a dual attention to both Student Thinking and Disciplinary Thinking, three teachers attended to Disciplinary Thinking. Mr Peterson’s written comment on Rob’s solutions is an example of feedback indicating a focus on Disciplinary Thinking:

*What motions are occurring during the fall of the tail light what forces are acting and in what directions?*

*What would happen if the bike was stationary?*

*What factors would influence how long it took to fall when stationary?*

*If the light did not break free where would it be each second?*
Draw successive positions of the fall in both these cases. 

Describe the continued motion. 

What influences the time it takes to fall? 

What influences how far along the road the light travels. 

What are the four equations of uniformly accelerated motion? 

How would you apply these? 

Also relate back to d versus t graph for uniform velocity and uniform acceleration. 

Solve again.

Mr Peterson provided a detailed explanation with much content when providing feedback on Rob’s solutions to the Bike task. Feedback with a lot of content and information may of course confuse or discourage the student. The bulk of Mr Peterson’s comments attended to Disciplinary Thinking, which is in contrast with his interpretations of Rob’s solutions(Table 5.4), which attended to both Student Thinking and Disciplinary Thinking. This was interesting as, from the perspective of the theoretical framework for this thesis discussed in Chapter 3, it might have been expected that, similar to his interpretations of Rob’s solutions, his feedback to Rob had a dual attention to Student Thinking and Disciplinary Thinking. This was suggested by Sanders et al. (1993) who conducted research on a momentum topic, and found that even though in some instances science teachers were aware of students’ difficulties, they used too much detailed explanation of the content and this confused both themselves and students.

However, the feedback of Ms Johnson fell into both Student Thinking and Disciplinary Thinking, as exemplified by:

... I would ask him to explain what he understands about the two components of motion so that we could discuss the basic concepts of projectiles. I would focus on this conceptual understanding and try to get him to imagine the object falling. Perhaps use analogies of jumping out of planes—doesn’t matter how fast the plane is, only how high above the ground before he jumps. Then I would spend time with a diagram and using arrows to assign directions, leading to a discussion of vectors – this didn’t
matter too much in this actual problem but is clearly a concept he doesn’t have.

The above comment suggests that Ms Johnson prefers to work with and discuss Rob’s current solutions and lead him to an understanding of new content. This illustrates the focus of her feedback on both the Student Thinking and Disciplinary Thinking categories (see the underlined words). Similarly, when interpreting Rob’s solutions she was attending to both Student Thinking and Disciplinary Thinking.

Ms Jenkins’s written comments also exemplify a dual Disciplinary Thinking and Student Thinking focus:

*Firstly I would give some positive reinforcement that he has worked effectively with the maths to get an answer. The attempt to draw a diagram is a good strategy too, that could be used to better effect. I would go through the little diagram and ask him to add some data to it, to try to elicit the fact that the initial velocity is zero in the vertical direction. Then I would use some other examples, including considering the motion from a different frame of reference, to draw out the fact that the initial vertical velocity is zero and that the two directions are independent of each other. I would follow up with a similar problem to be worked through, to see if he has made the required change in his thinking.*

The underlined words indicate a focus on the Student Thinking category. However, she also attended to the content used, and to the process of problem solving. Thus, Ms Jenkins’ feedback attended to both Student Thinking and Disciplinary Thinking, which was similar to her focus with respect to interpretations of Rob’s solution.

The general pattern identified in the data of each teacher’s feedback on Chris’s correct and Rob’s incorrect solutions to the Bike task are presented in Table 5.12.
Table 5.12  

Comparison of teachers’ foci when providing feedback on the correct and incorrect solutions to the Bike (standard) task

<table>
<thead>
<tr>
<th>Teachers’ Names</th>
<th>Teachers’ foci on Chris’s (correct) solution</th>
<th>Teachers’ foci on Rob’s (incorrect) solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms Jenkins</td>
<td>D\textsuperscript{T} A B ST</td>
<td>D\textsuperscript{T} A B ST</td>
</tr>
<tr>
<td>Mr Jackson</td>
<td>D\textsuperscript{T} A B ST</td>
<td>D\textsuperscript{T} A B ST</td>
</tr>
<tr>
<td>Ms Johnson</td>
<td>D\textsuperscript{T} A B ST</td>
<td>D\textsuperscript{T} A B ST</td>
</tr>
<tr>
<td>Mr Robinson</td>
<td>D\textsuperscript{T} A B ST</td>
<td>D\textsuperscript{T} A B ST</td>
</tr>
<tr>
<td>Mr Geraldton</td>
<td>D\textsuperscript{T} A B ST</td>
<td>D\textsuperscript{T} A B ST</td>
</tr>
<tr>
<td>Mr Peterson</td>
<td>D\textsuperscript{T} A B ST</td>
<td>D\textsuperscript{T} A B ST</td>
</tr>
<tr>
<td>Mr Pierce</td>
<td>D\textsuperscript{T} A B ST</td>
<td>D\textsuperscript{T} A B ST</td>
</tr>
<tr>
<td>Ms Chick</td>
<td>D\textsuperscript{T} A B ST</td>
<td>D\textsuperscript{T} A B ST</td>
</tr>
<tr>
<td>Ms Jones</td>
<td>D\textsuperscript{T} A B ST</td>
<td>D\textsuperscript{T} A B ST</td>
</tr>
<tr>
<td>Mr Sadler</td>
<td>D\textsuperscript{T} A B ST</td>
<td>D\textsuperscript{T} A B ST</td>
</tr>
<tr>
<td>Mr Richardson</td>
<td>D\textsuperscript{T} A B ST</td>
<td>D\textsuperscript{T} A B ST</td>
</tr>
</tbody>
</table>

Note: DT = Disciplinary Thinking, ST = Student Thinking. Where I coded the responses to be between A & B, I judged the teacher’s attention to be on both DT and ST. Where I coded the responses to be on A, I judged the teacher’s attention to be on both DT and ST but inclined to DT. Where I coded the responses to be on B, I judged the teacher’s attention to be on both DT and ST but inclined to ST.

Table 5.12 shows that each teacher’s feedback on Chris’s and Rob’s solution to motion tasks varies. For instance, it was shown that the focus of individual teacher feedback varied according to the type of task and student solution. When teachers’ feedback has the same focus on a student solution or explanation of the formula, the nature or detail of their comments is different. This suggests that the teachers’ PCKs differed. More teachers (eight) attended to both Student Thinking and Disciplinary Thinking when they provided feedback to Rob’s incorrect solution, than when they provided feedback to Chris’s correct solution to the standard (Bike) task (six).
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*Teachers’ feedback on the Karl’s incorrect solution to the non-standard task*

The focus of teachers’ written feedback on Karl’s solutions was analysed, with respect to Student Thinking, Disciplinary Thinking or both Student Thinking and Disciplinary Thinking and then illustrated in Table 5.13.

**Table 5.13  
Teachers’ foci when providing feedback on Karl’s (incorrect) solution to the Shoved Block (non-standard) task**

<table>
<thead>
<tr>
<th>Teachers’ names</th>
<th>Teachers’ foci</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms Jenkins (no comment)</td>
<td>A</td>
</tr>
<tr>
<td>Mr Jackson</td>
<td>A</td>
</tr>
<tr>
<td>Ms Johnson</td>
<td>A</td>
</tr>
<tr>
<td>Mr Robinson</td>
<td>A</td>
</tr>
<tr>
<td>Mr Geraldton</td>
<td>A</td>
</tr>
<tr>
<td>Mr Peterson</td>
<td>A</td>
</tr>
<tr>
<td>Mr Pierce</td>
<td>A</td>
</tr>
<tr>
<td>Ms Chick</td>
<td>A</td>
</tr>
<tr>
<td>Ms Jones</td>
<td>A</td>
</tr>
<tr>
<td>Mr Sadler</td>
<td>A</td>
</tr>
<tr>
<td>Mr Richardson</td>
<td>A</td>
</tr>
</tbody>
</table>

Note: DT = Disciplinary Thinking, ST = Student Thinking. Where I coded the responses to be between A & B, I judged the teacher’s attention to be on both DT and ST. Where I coded the responses to be on A, I judged the teacher’s attention to be on both DT and ST but inclined to DT. Where I coded the responses to be on B, I judged the teacher’s attention to be on both DT and ST but inclined to ST.

Table 5.13 shows that eight teachers fell into either Student Thinking or Disciplinary Thinking and only two teachers attended to both Disciplinary Thinking and Student Thinking when they provided feedback on Karl’s solution. Ms Jenkins did not provide sufficient comment, when providing feedback on Karl’s solution. Thus, her feedback was not classified.

Among the teachers whose feedback attended to Disciplinary Thinking, Ms Jones’s comments extracted from her interview are outlined below:
Int: how do you overcome this difficulty of the students [Karl and Mike]

Ms Jones: I’ll try it out. I’d actually get blocks of wood or some sort of – and I’d try different surfaces so I’d have heavy and light, I don’t know, wood, metal, whatever, try it with different surfaces so that it’s not just – I’d try it on one surface and then I’d record the results, then I’d try different surfaces to make sure that it applies - what I’m seeing on one surface applies on other surfaces.

It seems that Ms Jones rehearsed an empirical investigation to help Karl to determine the correct answer (see researcher’s underlined emphasis). It seems that her lack of confidence with the Shoved Block task led her to this “let’s find out together” style of explanation. Her feedback comments on Karl’s solutions show her Disciplinary Thinking focus. In contrast, Ms Jones attended to Student Thinking, when she interpreted Karl’s solutions (Table 5.6). This was interesting as, what might have been expected from the theoretical perspective of the thesis was totally different to the findings of Ms Jones’s interpretations of and feedback on student difficulties.

However, Ms Chick’s comments indicated a dual attention but an inclination toward the Student Thinking category when she provided feedback on Karl’s solution:

Yes. We need to ask lots of questions that are related to their experiences and related to the sort of experiments they’ve done. ... And as a whole I think we should be leaning more towards that than purely mathematical or algebraic type questions, because ...But at the same time we have to choose very carefully the situations that we use that they have in everyday life so that we don’t confuse them with this sort of thing, so that they get the right answer for the question but are then caught up in but that doesn’t make sense because my prior experience is something else. So we have to be very choosy about the situations, and I don’t know if I’m always successful, I don’t know if anybody else is always successful in doing that.
Although I interpret these comments as a dual attention to Student Thinking and Disciplinary Thinking, Ms Chick attended predominantly to student’s prior knowledge and she considered different prior experiences for different students, which is a focus on Student Thinking.

Mr Geraldton’s interview included the following excerpt:

*I will say to Karl well done, fantastic, very intuitive. Heading in the right direction. Let’s stop it. Look at that presumption that the larger than formal force to the small that component of friction. It seems that Karl tried to come up with some sort of coefficient friction ... summarises, so make the assumption the heavier it is the smaller that component would be doesn’t, make a lot of sense, so I wouldn’t take him through that. Unless he feels, unless he’s got some idea that what the other component going to be due to, and he feels that it is going to have major influence that’s surface area,*

These comments show that Mr Geraldton appreciated Karl’s solution. However, his feedback indicated a focus on Disciplinary Thinking, which is consistent with his focus applied when he interpreted Karl’s solutions (inclined to DT, see Table 5.6). Mr Geraldton could not correctly solve the task and he made some comments and explanations that indicated his misconceptions about motion and force. He reflected on his own solution strategy when interpreting and providing feedback on Karl’s solution, rather than attending to what he would say to Karl. This is also consistent with the research conducted by Sanders et al. (1993), which reported that when teachers taught or provided feedback on a topic outside their expertise, teachers’ explanations reference the teachers’ content knowledge in a specific topic, when they taught or provided feedback.

The general patterns that arose in the data of the teachers’ feedback to Karl and Rob’s incorrect solutions are presented in Table 5.14. The Table shows that although Rob and Karl both had misconceptions and both were unable to solve their respective tasks correctly (Bike and Shoved Block), there was a difference in the detail of the feedback the teachers gave. Many teachers attended to both Student Thinking and
Disciplinary Thinking, when providing feedback to Rob’s solution, but this was not the case with the teachers’ feedback on Karl’s solution.

Table 5.14
Comparison of teachers’ foci when providing feedback on Rob’s and Karl’s solutions

<table>
<thead>
<tr>
<th>Teacher’s names</th>
<th>Teachers’ foci on Rob’s incorrect solution to the Bike task</th>
<th>Teachers’ foci on Karl’s incorrect solution to the Shoved Block task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms Jenkins</td>
<td>DT A &amp; B ST</td>
<td>DT A &amp; B ST</td>
</tr>
<tr>
<td>Mr Jackson</td>
<td>DT A &amp; B ST</td>
<td>DT A &amp; B ST</td>
</tr>
<tr>
<td>Ms Johnson</td>
<td>DT A &amp; B ST</td>
<td>DT A &amp; B ST</td>
</tr>
<tr>
<td>Mr Robinson</td>
<td>DT A &amp; B ST</td>
<td>DT A &amp; B ST</td>
</tr>
<tr>
<td>Mr Geraldton</td>
<td>DT A &amp; B ST</td>
<td>DT A &amp; B ST</td>
</tr>
<tr>
<td>Mr Peterson</td>
<td>DT A &amp; B ST</td>
<td>DT A &amp; B ST</td>
</tr>
<tr>
<td>Mr Pierce</td>
<td>DT A &amp; B ST</td>
<td>DT A &amp; B ST</td>
</tr>
<tr>
<td>Ms Chick</td>
<td>DT A &amp; B ST</td>
<td>DT A &amp; B ST</td>
</tr>
<tr>
<td>Ms Jones</td>
<td>DT A &amp; B ST</td>
<td>DT A &amp; B ST</td>
</tr>
<tr>
<td>Mr Sadler</td>
<td>DT A &amp; B ST</td>
<td>DT A &amp; B ST</td>
</tr>
<tr>
<td>Mr Richardson</td>
<td>DT A &amp; B ST</td>
<td>DT A &amp; B ST</td>
</tr>
</tbody>
</table>

Note: DT= Disciplinary Thinking, ST= Student Thinking. Where I coded the responses to be between A & B, I judged the teacher’s attention to be on both DT and ST. Where I coded the responses to be on A, I judged the teacher’s attention to be on both DT and ST but inclined to DT. Where I coded the responses to be on B, I judged the teacher’s attention to be on both DT and ST but inclined to ST.

Table 5.14 also shows that only a few teachers’ responses fell into both the Disciplinary Thinking and Student Thinking categories when they provided feedback on Karl’s solutions to a non-standard task. This was not the case when the teachers provided feedback on Rob’s and Chris’s solutions for the standard task. This suggests that the type of task itself influenced the teachers’ responses to student solutions. This reflected teachers’ distinctive PCKs and their teaching experience. As noted earlier, experience with teaching a task may provide insights into student thinking about the task that, together with an appropriate level of CK, enable a teacher to provide feedback that is both Student Thinking and Disciplinary Thinking.
5.5.2 Teachers’ feedback with respect to the type of task (standard and non-standard)

In order to fully address the second research question, it is important to compare the general patterns arising from the teachers’ feedback on the students’ solutions to the standard (Bike) and non-standard (Shoved Block) tasks. A detailed analysis is presented in Appendix D of each teacher’s focus across the solutions of three students to the standard (Bike) task and the teacher’s focus across two student solutions to the non-standard (Shoved Block) task. Each teacher’s overall feedback on three students’ solutions to the Bike task was categorised approximately across Student Thinking, Disciplinary Thinking or both Student Thinking and Disciplinary Thinking in Table 5.15.

Table 5.15
Comparison of teachers’ foci when providing feedback on the students’ solutions to the Bike (standard) and the Shoved Block (non-standard) tasks

<table>
<thead>
<tr>
<th>Teachers’ names</th>
<th>Teachers’ feedback on students’ solutions to the Bike task</th>
<th>Teachers’ feedback to students’ solutions to the Shoved Block task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr Jackson</td>
<td>DT: A, ST: B</td>
<td>DT: A, ST: B</td>
</tr>
<tr>
<td>Mr Robinson</td>
<td>DT: A, ST: B</td>
<td>DT: A, ST: B</td>
</tr>
<tr>
<td>Mr Geraldton</td>
<td>DT: A, ST: B</td>
<td>DT: A, ST: B</td>
</tr>
<tr>
<td>Mr Peterson</td>
<td>DT: A, ST: B</td>
<td>DT: A, ST: B</td>
</tr>
<tr>
<td>Mr Pierce</td>
<td>DT: A, ST: B</td>
<td>DT: A, ST: B</td>
</tr>
<tr>
<td>Mr Sadler</td>
<td>DT: A, ST: B</td>
<td>DT: A, ST: B</td>
</tr>
<tr>
<td>Mr Richardson</td>
<td>DT: A, ST: B</td>
<td>DT: A, ST: B</td>
</tr>
</tbody>
</table>

Note: DT = Disciplinary Thinking, ST = Student Thinking. Where I coded the responses to be between A & B, I judged the teacher’s attention to be on both DT and ST. Where I coded the responses to be on A, I judged the teacher’s attention to be on both DT and ST but inclined to DT. Where I coded the responses to be on B, I judged the teacher’s attention to be on both DT and ST but inclined to ST.
Table 5.15 shows that when providing feedback on students’ solutions to the standard (Bike) task most teachers attended to both the Student Thinking and the Disciplinary Thinking. Table 5.15 also demonstrates the similarities and differences between each teacher’s responses, with respect to the standard and non-standard tasks, when they provided feedback to the students. Table 5.15 shows that compared to the standard task, teachers’ foci shifted from both Student Thinking and Disciplinary Thinking towards either Student Thinking or Disciplinary Thinking when they provided feedback on students’ solutions to the non-standard task.

Summary:

A majority of teachers attended to both Student Thinking and Disciplinary Thinking, when interpreting correct and incorrect student solutions to the Bike task (Tables 5.3-5.5). However, when providing feedback on the correct solutions to the Bike task, only six teachers (Mr Jackson, Ms Johnson, Mr Geraldton, Mr Peterson, Ms Chick, and Mr Sadler) (Table 5.10) attended to both Student Thinking and Disciplinary Thinking, and when providing feedback on the incorrect student solutions to the Bike task, eight teachers (Ms Jenkins, Mr Jackson, Ms Johnson, Mr Robinson, Mr Geraldton, Mr Pierce, Ms Chick, Mr Richardson) (Table 5.11) attended to both Student Thinking and Disciplinary Thinking.

Comparing teachers’ feedback on students’ solutions to the standard and non-standard tasks, it seems that teachers’ foci varied from dual attention to both Student Thinking and Disciplinary Thinking towards either Student Thinking or Disciplinary Thinking. It could reasonably be claimed that the teachers needed a richer content knowledge in the theory of motion in order to solve the non-standard task (Shoved Block) than is required for the standard tasks (Bike and Glider). This suggests that teachers’ feedback may reference their level of content knowledge.

The physics curriculum in Year 11-12 in Victoria excludes non-standard tasks that require a non-standard or heuristic application of the mathematics to the physics theory, and this causes teachers to be unfamiliar with this type of task. Thus, when solving the Shoved Block task, some teachers reverted to using empirical problem solving which indicates a conceptual focus on Disciplinary Thinking, rather than the using standard models they knew how to share with students.
It appears that in interpretations of student solutions to both standard and non-standard tasks, teachers gave dual attention to Student Thinking and Disciplinary Thinking. However, when providing feedback on the same student solutions, different teachers attended more to either the Disciplinary Thinking or Student Thinking category. That is they were predisposed to one category of response over the other which may make them less responsive to individual student difficulties. This finding supports observation by Smith and Neale (1989, 1991) that a teachers’ knowledge of students’ difficulties does not necessarily lead to appropriate teacher response(s).

5.5.3 Categorizations of teachers’ feedback on the students’ explanations of the
formula: $v = v_0 + at$

Each teacher was asked to provide feedback on the explanations by three students (see section 5.2.3, Mary’s, Michelle’s, and Simon’s solutions) of the formula $v = v_0 + at$. In order to address the second research question, concerned with teacher feedback, it is important to explore the general patterns arising from the teachers’ feedback to the students’ explanations of the formula, illustrated in Table 5.16.

Table 5.16 shows that when providing feedback on the students’ explanations of the formula $v = v_0 + at$, most teachers’ responses fell into both Student Thinking and Disciplinary Thinking categories.
Chapter 5: Results

Table 5.16
Teachers’ overall foci when providing feedback on students’ explanations of the formula: \( v = v_0 + at \)

<table>
<thead>
<tr>
<th>Teachers’ names</th>
<th>Teachers’ foci</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms Jenkins</td>
<td>DT: A, B, ST</td>
</tr>
<tr>
<td>Mr Jackson</td>
<td>DT: A, B, ST</td>
</tr>
<tr>
<td>Ms Johnson</td>
<td>DT: A, B, ST</td>
</tr>
<tr>
<td>Mr Robinson</td>
<td>DT: A, B, ST</td>
</tr>
<tr>
<td>Mr Geraldton</td>
<td>DT: A, B, ST</td>
</tr>
<tr>
<td>Mr Peterson</td>
<td>DT: A, B, ST</td>
</tr>
<tr>
<td>Mr Pierce</td>
<td>DT: A, B, ST</td>
</tr>
<tr>
<td>Ms Chick</td>
<td>DT: A, B, ST</td>
</tr>
<tr>
<td>Ms Jones</td>
<td>DT: A, B, ST</td>
</tr>
<tr>
<td>Mr Sadler</td>
<td>DT: A, B, ST</td>
</tr>
<tr>
<td>Mr Richardson</td>
<td>DT: A, B, ST</td>
</tr>
</tbody>
</table>

Note: DT = Disciplinary Thinking, ST = Student Thinking. Where I coded the responses to be between A & B, I judged the teacher’s attention to be on both DT and ST. Where I coded the responses to be on A, I judged the teacher’s attention to be on both DT and ST but inclined to DT. Where I coded the responses to be on B, I judged the teacher’s attention to be on both DT and ST but inclined to ST.

Ms Chick’s feedback indicated a focus on both Student Thinking and Disciplinary Thinking, as exemplified by her comments on Michelle’s solution:

*Give her more practice with this equation to help her formulate a more coherent answer to the question. She has some idea of what the equation means, but needs more clarity which could be provided through more practice. She currently doesn’t have a good grasp of how the equation can apply to a practical situation, so again more practice could help enhance her understanding. I would also spend time talking to her about her answers to questions solved using the equation to ensure she sees the initial velocity and the change in velocity caused by the acceleration.*
The above comments indicate dual attention to Student Thinking and Disciplinary Thinking. While Ms Chick placed emphasis on Michelle’s understanding of the equation, she did not explain the process of her suggested feedback (that is doing the practice with this equation). Ms Chick justified her suggested feedback as referring to Michelle’s “need [for] more clarity”, which is an attention to Student Thinking. In response to the question concerned with Ms Chick’s justification of her suggested feedback, she wrote:

She has understood the explanation provided to her and can repeat this explanation back, but she doesn’t have a deeper understanding. She needs to use the equation and see how it works in different situations to get a better grasp of the physics.

This comment indicates that Ms Chick justified her suggested feedback by having dual attention to Disciplinary Thinking and Student Thinking (see underlined words).

Table 5.16 also shows that Ms Jenkins’s responses had dual attention to Disciplinary Thinking and Student Thinking, inclined towards Student Thinking, when providing feedback on the students’ explanations of the formula. For example, she commented on Michelle’s explanation of the formula:

In feedback I would commend Michelle for her good understanding and try to get her to express her understanding more fluently.

Some practical representations would help cement Michelle’s good understanding. She could use a motion sensor in more complex ways, such as for a bouncing basketball, and see how the velocity changes in the different parts of the motion. She could then make the link to the acceleration being given by the gradient of the graph and see how that changes with the upwards and downwards motion, which would tie in with her understanding as expressed. I would encourage her to describe what is going on each time, to improve her fluency of explanation.
These comments attended to both Disciplinary Thinking and Student Thinking, (see underlined words) when she provided feedback on Michelle’s explanations of the formula. In her justification of the suggested feedback, Ms Jenkins wrote:

Michelle is well on the way and just needs more reinforcement, which some practical work would provide.

However, Mr Sadler’s feedback on all students’ explanations of the formula attended to Disciplinary Thinking diagnosis and treatment. For example, he commented on Michelle’s explanation of the formula:

Ask what she means by ‘correction on accel’. Ensure she knows that the ‘at’ term represents the change in vel.
To know what the individual terms in the equation mean + how they fit together

In response to Mary, Mr Sadler wrote in a similar vein:

Use correct terms. Instead of starting bit, say initial velocity.
And replace movement bit with increase in vel.
Treat each term separately.
Will clear the ideas in her head and sort them into logical steps.

The above comment indicates attention to student thinking or active engagement is not stereotypically addressed. Mr Sadler’s feedback to Simon in the interview was:

...He just needs clarification about what he ... he needs..., positive feedback, ... needs to say to him yeah well done, you’re right.

It seems that, Mr Sadler appreciated Simon’s explanations of the formula, because he believed that Simon did not need to understand the formula (see 5.4.3, Mr Sadler’s interpretation of Simon’s explanation of the formula $v = v_0 + at$). This finding suggests Magnusson’s (1991) observation that ignorance of student difficulties will prevent meaningful response to those difficulties and ultimately hinder student understanding.

5.6 Summary

This chapter reported data derived from the Initial Analysis, and the patterns or relationships derived from the Comparative Analysis. The teachers’ written and verbal
comments were analysed across the Disciplinary Thinking and Student Thinking categories. Some teachers’ responses were more extensive and comprehensive than others. Through the initial coding and analysis, each teacher’s comments were reduced, coded, summarised, and then presented in Appendix D. The foci of each teacher’s response were identified and discussed by looking and analysing a word, a phrase, a sentence, or a paragraph or whole teacher comments to a student. It was possible to give a label to a teacher by looking across all teachers’ comments.

Responses from eleven physics teachers to the PCQ and PCI were analysed and reported in four sections: (1) teachers’ backgrounds derived from the third part of the questionnaire, (2) teacher beliefs about teaching approach and learning the linear motion task, (3) teachers’ interpretations of student solutions, and (4) teachers’ feedback on student solutions.

Teachers’ backgrounds include demographic data and the level of teacher CK in the area of linear motion. Overall, the teachers’ beliefs about teaching and learning motion were categorised into three groups (explained in section 5.3.4). These groups comprised (a) the teachers with focus on Student Thinking and Disciplinary Thinking, (b) the teachers who attended to Disciplinary Thinking, and (c) teachers who provided general comments that were difficult to interpret and categorise. As teachers did not provide a rich data about the Glider task, the relevant findings are briefly discussed in Chapter 6, section 6.6.3.

The data from teachers’ written and oral comments in the questionnaire and interview showed that a majority of teachers attended to both Student Thinking and Disciplinary Thinking, when interpreting correct and incorrect student solutions to the Bike (standard) task. This is consistent with the assumption explained in Chapter 3 that ‘good’ teaching involves attention to both Student Thinking and Disciplinary Thinking. However, it was not the case with the Shoved Block (non-standard) task, suggesting that skilled knowledge associated with attending to Student Thinking and Disciplinary Thinking are interdependent in different ways with different tasks.

With respect to teacher feedback on the correct solution to the Bike (standard) task, only six teachers attended to both the Student Thinking and Disciplinary Thinking categories. However, with respect to teacher feedback on the incorrect student solutions to the task, eight teachers attended to both the Student Thinking and Disciplinary
Thinking categories, which is consistent with what might have been expected from the theoretical perspective of the thesis. With respect to teacher feedback on the Shoved Block (non-standard) task, many physics teachers were not able to attend to both Student Thinking and Disciplinary Thinking.

The emergent differentiation of the personal professional identities of the Physics teachers in this study, with respect to their skilled knowledge and beliefs about teaching motion is itself interesting and I sense important and will be included in discussion of the influences on teachers’ feedback in the next chapter.
Chapter 5: Results
Chapter 6: Discussion Of Teacher Responses On Student Solutions

6.1 Introduction

In the previous chapter the data collected from the problem-based interview and questionnaire – with respect to the teachers’ backgrounds, beliefs, interpretations of, and feedback on student responses – were analysed and presented. This chapter has two major purposes: to address the research questions posed at the outset and to interpret the research findings within the theoretical framework developed in this study. The implications and limitations of this research are explained in Chapter 7.

RESEARCH QUESTIONS

The focus of this study was to explore the nature of teacher feedback, and in order to address this important aspect of teaching, there was a need to understand teacher interpretation of student solutions that underpins the feedback they gave to students. The research questions addressed by this study were:

1- How do high school physics teachers interpret correct and incorrect student solutions to standard textbook and incorrect student solutions to non-standard motion tasks in physics, and on student explanations of the physics formulae?

2- How do high school physics teachers provide feedback on correct and incorrect student solutions to standard textbook and incorrect student solutions to non-standard motion tasks in physics, and on student explanations of the physics formulae?

It needs to be noted that the second research question provides the main point of discussion in this study. In order to address the above research questions, it is important to briefly revisit and explain the theoretical framework developed for this research. The relevant literature (see Chapter 3) was drawn together into one coherent framework which describes how good physics teachers interpret and importantly, provide feedback on, student responses to the motion tasks. The theoretical framework for this study proposes that physics teachers in their everyday practice adopt a dual focus on both the students’ prior thoughts and the formal concepts being introduced, identified here as ‘Student Thinking’ and ‘Disciplinary Thinking’ respectively, when interpreting and providing feedback on student responses to the different motion tasks. It was also an assumption that the teachers who had a high level of content knowledge on the topic of linear motion would provide exemplary feedback to students which focused on both
students’ prior thoughts/beliefs and the disciplinary content of the motion topic, in the quest to promote students’ conceptual development.

Two types of teaching-learning problems or tasks, standard and non-standard, defined the context of the enquiry. The responses of (hypothetical) students to these tasks were categorized as correct or incorrect. The coded teacher accounts presented in Chapter 5 of each teacher’s individual responses and the collective interpretations of and feedback on all student solutions to the standard and non-standard tasks and student explanations of the formula $v = v_0 + at$ will be reviewed in section 6.2.

According to the theoretical framework used for this study and detailed in Chapter 3, three components of teacher pedagogical content inform teacher feedback. These are teachers’ interpretations of student solutions to standard tasks, teachers’ content knowledge, and their dispositional knowledge or beliefs about the learning and teaching of motion. This suggests examining the relationships between these three components of pedagogical content knowledge and teacher feedback, where the student offered different solutions to the Bike task, particularly an incorrect solution. These relationships are discussed in sections 6.3 - 6.5. For each teacher, the relationships in their accounts between each feature of their skilled knowledge and their feedback on the student’s incorrect solutions to the Bike (standard) task were examined, as will be elaborated in section 6.6. A review of these findings will be presented in section 6.7.

6.2 Variations among the eleven teachers

Teacher interpretations of, and feedback on, student solutions to the standard and non-standard tasks and student explanations of the formula $v = v_0 + at$ were outlined in 5.4 and 5.5. The variations between teachers’ responses are taken to represent differences in their PCK. These variations are summarized and discussed below.

Teachers’ interpretations:

Overall, the findings of this study, which explores some aspects of teachers’ intentional or skilled knowledge, showed that a majority of teachers attended to both Student Thinking and Disciplinary Thinking, when interpreting correct and incorrect student solutions to the standard task and student explanations of the formula.

However, with respect to teachers’ accounts of their interpretations of students’ solutions to the non-standard task, which required a richer content knowledge, many
teachers did not attend to both the dimensions of Student Thinking and Disciplinary Thinking, but focused on either one of them. This is not surprising with regards to the teachers who did not solve the task, as some literature (e.g. Gess-Newsome, 1999; Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001) has suggested that teachers who have a low content knowledge have difficulty teaching conceptually in this area, identifying their students’ conceptions and take a more procedural approach which lends itself to a literal algorithmic approach. The five teachers who solved the task made very brief or general comments. Perhaps, because they had not taught the non-standard task before, they were not familiar with student thinking and misconceptions in this area, and so offered to the researcher only general comments on their teaching experience in this area of student learning. It is also possible that the teachers, who focused on either Student Thinking or Disciplinary Thinking, understood and interpreted the student’s response to the non-standard motion task as they themselves understood the particular application of motion theory; that is, only the broad first principles. Thus they revisited these principles of Disciplinary Thinking. Hence their skilled knowledge was restricted by their low content knowledge or lack of discursive practice transacting this type of task.

Teachers’ feedback:

With respect to teacher feedback on the correct solution to the standard (Bike) task, only six teachers (Mr Jackson, Ms Johnson, Mr Geraldton, Mr Peterson, Ms Chick, and Mr Sadler) showed both Student Thinking and Disciplinary Thinking in their response. However, with respect to teacher feedback on the student incorrect solution, eight teachers (Ms Chick, Ms Johnson, Ms Jenkins, Mr Jackson, Mr Robinson, Mr Geraldton, Mr Pierce, and Mr Richardson) attended to both the Student Thinking and Disciplinary Thinking categories. Perhaps the teachers were inclined to think there was less need to provide diagnostic feedback when they judged a student had given the correct answer, which they took as evidence of comprehension of the concepts and processes required to solve the task meaningfully.

The majority of teachers attended to both Student Thinking and Disciplinary Thinking, when providing feedback on all students’ explanations of the formula \( v = v_0 + at \). This result is not unexpected given the formula is a standard part of
the kinematics component of introductory physics courses such as that which the teachers taught. Detailed comments from some teachers will be discussed in section 6.5.

It should be noted that most teachers’ feedback on incorrect student solutions to the shoved Block (non-standard) task was too brief and vague to reveal any pattern. Consequently, the study focused on teacher feedback on the hypothetical student’s solution to the Bike (standard) task.

To summarize, the above findings suggest that each teacher’s interpretation of, and feedback on, all student solutions to motion tasks, and explanations of the formulae, is unique. For instance, it was shown that the focus of individual teacher feedback varied according to the type of task and solution. This suggests that each teacher’s PCK is dynamic and responsive to different teaching situations. Although this is embedded in the idea of teacher’s skilled knowledge or PCK in some literature and was expected, this research provides examples that illustrate the nature of teacher knowledge viz. how the representation of formal physics concepts and knowledge about responses to student thoughts/views interact.

It was also seen that while some teachers’ interpretations and feedback may have attended to the same features in the student solutions to the motion task or explanation of the formula, the nature or detail of their comments was different. This suggests that the teachers differed, and the study sheds light on the differences in the professional identities of the eleven teachers, with respect to their knowledge and beliefs about motion problem solving and student thinking. While some teachers attended to Disciplinary Thinking by referencing the process of problem solving, others who attended to Disciplinary Thinking referenced the concepts used in the problem solving.

### 6.3 Relationships between teachers’ interpretations and feedback

Some literature (e.g., Magnusson et al., 1999) has suggested that the nature and quality of feedback teachers provided could be related to their perceptions and judgments of students’ broad understandings of the topic and specific conceptual difficulties, and also the length of the teachers’ experience. The relationships between teachers’ feedback and their interpretations of student solutions to the Bike task are discussed here.

Out of ten teachers whose interpretations of the incorrect solution to the Bike task had dual attention to Student Thinking and Disciplinary Thinking, eight teachers attended to both Student Thinking and Disciplinary Thinking, when providing feedback.
With respect to the correct solution to the task, out of eleven teachers whose interpretations gave dual attention to both Student Thinking and Disciplinary Thinking, six teachers attended to both Student Thinking and Disciplinary Thinking in their feedback.

In short, compared to teachers’ interpretations, teachers’ foci moved away from dual attention to both Student Thinking and Disciplinary Thinking when providing feedback on correct and incorrect student solutions to Bike task. That is, teachers’ interpretations might explore and analyse the students’ difficulties, but this was not always reflected, either in nature or detail, in meaningful feedback. Although the assumption in this study was that dual attention to both Student Thinking and Disciplinary Thinking would promote meaningful problem solving by students, this was not always the case, explained in 6.6.2. This highlights the importance of teachers having the appropriate skilled knowledge and understanding of both content and student learning in order to promote student understanding of concepts and use of meaningful problem solving strategies.

Some literature (Berg & Brouwer, 1991; Gerace & Beatty, 2005; Magnusson, Krajcik & Borko, 1999) has suggested that teacher often experienced considerable challenges in responding to student difficulties in solving standard tasks. The current study of teacher accounts suggests the teacher difficulties are deeply embedded in their identity formation as teachers of Physics. These difficulties have been described in the literature as rising from inadequate dispositional knowledge in student’s prior learning, or from poor teacher propositional or content knowledge. The former has been related to an adherence to a traditional teaching role which is essentially formal logical and didactic, rather than constructivist. The latter suggests a practical rather than expressive use of language in feedback arises from an inadequate training in the discipline.

6.4 Relationships of teacher content knowledge and feedback

The literature reviewed in Chapters 2 and 3 proposes that a rich teacher CK underpins the teaching of meaningful problem solving in physics. Gess-Newsome (1999) for example argues that “Teachers with strong conceptual knowledge have more detailed knowledge of the topic, more connections, and relationships to other topics, and can easily draw upon this knowledge in teaching and problem solving situation” (p. 63). This suggests that, in the context of this study, the teachers who had a richer content
knowledge in the linear motion topic should be able to link the mathematics and
formulae with the motion concepts and problem solving strategy in the physics context,
when providing feedback on the students’ difficulties in the motion tasks. This is
consistent with the ideas of Sherin (2001) and Clement (1994), who link the
development of student understanding of physics formulae and problem solving
strategies with effective instruction.

In the current study overall, a variety of relationships was found between the level of
teacher’s propositional or content knowledge and attention given to both Student
Thinking and Disciplinary Thinking in their interpretations of, and feedback on
students’ correct and incorrect solutions. The teachers’ responses to the incorrect
solution where the student had difficulty incorrectly solving the Bike task are revealing
here.

Out of the five teachers who demonstrated a high level of CK, four (Mr Robinson, Ms
Jenkins, Ms Chick, Ms Johnson) attended to both Disciplinary Thinking and Student
Thinking when interpreting and providing feedback on the student’s learning difficulty.
This was consistent with the three assumptions of this study (see Chapter 3), and
supports the relationship proposed between teachers’ CK and their feedback on
students’ difficulties by Loughran et al. (2001) and Sanders, Borko, and Lockard
(1993). Only one teacher (Mr Peterson), with a high level of CK, attended only to
Disciplinary Thinking, when providing feedback on the student’s incorrect solution to
the standard task. However, of the six teachers who demonstrated a low and medium
level of CK, three teachers focussed on Student Thinking and Disciplinary Thinking,
when providing feedback on the student response.

The above findings suggest that the relationship between a teacher’s responses and
their content knowledge may be more complex than has been suggested in some
literature. This will be elaborated in section 6.6.2.

6.5 Relationships between teacher dispositional knowledge or beliefs about
teaching and learning of motion and feedback

As explained in Chapter 2 and 3, teacher feedback to student is related to teacher
dispositional knowledge or beliefs about the teaching and learning of motion. The
relationships between teacher dispositional knowledge about teaching problem solving
as well as formulae and their feedback are explained here.
Teachers’ dispositional knowledge or beliefs about teaching and learning motion problem solving and feedback

As suggested by the research discussed in Chapters 2 and 3, good physics teachers will attempt to link understanding of the physics concepts with the mathematics involved in problem solving to provide a meaningful approach to solving and teaching motion tasks. Magnusson et al. (1999) proposed that teacher knowledge of activities such as problem solving strategies guided students’ understanding of problem solving. They argued the need for demonstrations or experiments in teaching a specific topic, such as linear motion, to illustrate “the conceptual power” of the physics theory (pp. 111-113). However, the teachers’ accounts in this study showed they followed algorithmic procedures and computational routines rather than constructivist approaches, and most teachers also did not focus on providing a meaningful problem solving strategy when introducing strategies to teach motion problem solving. Instead, they said they sought to demonstrate the applicability of a particular algorithm and to increase student facility in its use in the specific task. The teachers’ accounts of their material and symbolic use of motion experiments also indicated that they placed emphasis on the procedural aspects of the experiments. They did not plan or envisage the investigation as a conceptual transaction with the students. They provided and explained the structure of the suggested experiment, and then asked the students to do the experiment step by step, so that theoretical relationship of principles could be seen to be proved to be true. Some teachers referred to classroom investigations as serving a strategic apodictic or demonstrative function when they observed students had conceptual difficulties with grammatical explanations; they were disposed to offer student direct experience as proof or the foundation of certainty. But as Wittgenstein (1975) points out a demonstration can at best be an invitation to a discussion.

Eight out of eleven teachers attended to both Student Thinking and Disciplinary Thinking (see 5.3.4) when explaining their dispositions or beliefs about teaching and learning motion, which is associated with the attention they represent in their feedback on the incorrect solution to Bike task. This shows a relationship between the teachers’ beliefs and intentions in their account of their teaching of problem solving and the feedback they gave to the student, which is consistent with the assumption presented in Chapter 3. However, all this feedback did not promote students’ understandings of the concepts or their use of meaningful problem solving strategies. The differences in the
feedback of teachers who gave dual attention to both Student Thinking and Disciplinary Thinking are detailed in section 6.6.2.

Teachers’ beliefs about what makes a good physics teacher showed that some, for example Mr Peterson, focused on the importance of being “somebody who really enjoys the subject .... It has nothing to do with their [students] ability” (see 5.2), a comment which I interpreted, as did Redish (1994), to have a content centred disposition. For Mr Robinson, by contrast, being a good physics teacher was being “able to put yourself in the shoes of the students” (see 5.2). While Mr Peterson appears to perceive the central challenge of physics teaching to reside in constructing a representational monologue about physics, Mr Robinson appears to perceive the challenge to be the constructing of a responsive dialogue with his students. The beliefs of these two teachers’ about their professional identity were reflected in their feedback to students. While Mr Peterson attended exclusively to Disciplinary Thinking, Mr Robinson attended to both Student Thinking and Disciplinary Thinking.

**Teachers’ dispositional knowledge or beliefs about teaching and learning the motion formula and feedback**

Sweller (1999) showed that full grammatical understanding of a formula such as \( v = v_0 + at \) requires good conceptual understanding of the component physical entities and their units of measurement and is difficult. The findings of the current research indicated that the teachers generally attempted to show a particular formula was appropriate to a familiar context. Each symbol in the mental operation of \( v = v_0 + at \) was identified as a label for a particular word/s used to describe some aspects of the context or problem; “t” for example may mean 3 seconds in a particular context. However, as Sweller (1999) suggests, the symbol ‘at’ or ‘\( v_0 + at \)’ is not so easily made meaningful.

Sherin (2001) proposed that students should be taught appropriate mental “schema” to meaningfully employ them in different contexts of physics but no teachers in this study were disposed to such a formal approach.

Some physics teachers such as Mr Geraldton and Mr Richardson indicated that they did not attempt this common sense description of the meaning of physics formulae when teaching kinematics in their physics classrooms. It seems they had experienced and understood the challenge of teaching the meaning of physics formulae, but did not
believe that they knew how to or that the students were capable of understanding the representational meaning in the equation (section 5.2). They resolved this by using a pragmatic teaching approach in which the equation was presented as a procedural paradigm to be followed.

However, some teachers such as Ms Johnson and Ms Chick used a constructivist approach and focused on understanding the formula when explaining to the researcher their approach for teaching the formula $v = v_o + at$. For example, Ms Johnson put the formula into common language, when she said:

*I would write/speak it in words and then introduce the algebra as a simple representation of this thinking ie, initial conditions and then a change in this speed due to the acceleration...*

She did this rather than using the algebraic form of the equation, which is the traditional approach used by most teachers. This raises questions about the teachers’ conceptions of the role of language in communicating meaning to students. Perhaps the teachers seek to minimise or reduce the language used to label abstract entities and concepts, so that the activity of problem solving becomes code recognition and a student’s incorrect solution can be seen as coding errors. For instances student may confuse certain words in the problem as code for $v$, rather than $v_o$ or $a$ in the formula. Ms Chick also spoke of the challenge to respond to students’ individual understandings of motion formulae. Her experience of the differences between students perhaps predisposed her to attend to both Student Thinking and Disciplinary Thinking, as Gerace and Beatty (2005) have proposed. Both Ms Johnson’s and Ms Chick’s beliefs about teaching and learning motion problem solving and the use of formulae were reflected in their feedback on both correct and incorrect student solutions to the Bike task.

Mr Peterson attended to the representation of formal concepts through applying a mathematical approach including describing several graphs and formulae, when introducing the formula: $v = v_o + at$ (section 5.3.3). Mr Peterson’s belief about teaching formulae was reflected in his suggested feedback on the incorrect student solution in solving the Bike task where he attended to representing formal physics concepts through using graphs.
As explained in section 6.4 and 6.5, there are a variety of relationships between teachers’ feedback on student solutions to the Bike task, and the two components of teacher PCK; that is, teachers’ content knowledge and their beliefs about teaching and learning motion. With respect to the teachers’ feedback on incorrect student solutions to the Bike task, these relationships are detailed in 6.6.1.

### 6.6 The teaching of motion tasks

In this section, drawing on each Physics teacher’s accounts of their teaching intentions and responses to students, I discuss two forms of teacher knowledge, teachers’ dispositional knowledge or beliefs about both their teaching approach and student learning, and teachers’ propositional or content knowledge, in problem based teaching of linear motion. In section 6.6.1, I explore three patterns of teacher PCK, based on the relationships between the interrelated factors influencing the feedback of individual teachers. Differences in teachers’ feedback that focussed on both Student Thinking and Disciplinary Thinking will be explained in 6.6.2. Teachers’ PCK across the types of tasks are discussed in section 6.6.3. Teachers’ PCK and CK as related to their background are also briefly discussed in 6.6.4.

#### 6.6.1 Factors related to teachers’ feedback

The teachers were grouped by their feedback responses on incorrect student solutions to the Bike task, teachers’ personal dispositions or beliefs about teaching and learning motion and teachers’ content knowledge. These groupings are explained below.

1. To some teachers (e.g., Mr Peterson, Mr Richardson, Mr Geraldton, and Mr Pierce, Mr Jackson) their beliefs about the teaching and learning of motion problem solving, rather than specific content knowledge, were more consistently reflected in their written feedback. The authority of these teachers’ dispositional knowledge or beliefs about teaching motion tasks and the use of the formulae seem to structure their feedback.

   In this group only Mr Peterson’s CK was classified at a high level, and his beliefs about teaching and learning problem solving seemed to be the main prompt for his focus on Disciplinary Thinking in his feedback on incorrect solutions to the Bike task. It is interesting that despite his 35 years teaching experience, Mr Peterson did not attend to Student Thinking. His PCK, as reflected in his feedback, was shaped by beliefs about teaching motion tasks and the use of the formulae that were grounded in the authority of
the physics discipline, as represented in curriculum material. Four teachers (Mr Geraldton, Mr Richardson, Mr Pierce, and Mr Jackson) who were classified as being at a low level of CK, attended to both Student Thinking and Disciplinary Thinking in their feedback, which is consistent with their focus, when explaining their beliefs about teaching and learning motion. Although Mr Jackson’s beliefs about teaching and learning motion were not classified in any specific category (see 5.3.4), the detail and nature of his beliefs were reflected in his feedback.

(2) To some teachers (Ms Jones and Mr Sadler), there was no strong relationship found between their feedback and their beliefs about teaching and learning motion. This is consistent with Pajares’ (1992, p. 326) observation that: “Beliefs strongly influence perception, but they can be an unreliable guide to the nature of reality”. Here, the perceived reality was the necessity of ‘correcting’ grammatical misrepresentations in student responses. I felt these teachers’ reported beliefs about teaching motion tasks and the use of the formulae were an ‘unreliable guide’ to interpreting their suggested feedback.

Although Ms Jones was predisposed to a belief that she should attend to both Student Thinking and Disciplinary Thinking with respect to the learning and teaching of motion, her feedback was focused only on Disciplinary Thinking. This may have been related to her low CK and/or lack of experience in explaining the meaningful use of the formulae. While Mr Sadler’s beliefs about learning and teaching motion were brief and vague, he attended to representation of the content used, and/or the process of problem solving and experiment, when providing feedback. This may be related to his low CK and/or having fewer years (three years) of experience in teaching physics.

(3) For some teachers (e.g. Ms Chick, Ms Johnson, Mr Robinson, and Ms Jenkins) both their CK and beliefs about the teaching and the learning of motion problem solving were associated with their attention to both ST and DT in their feedback. These teachers were predisposed in knowledge and practice to link meaningful understanding of the formulae to their teaching of physics problem solving. They attended to both Student Thinking and Disciplinary Thinking in a way which could be described as a dialogical conceptual change strategy. All teachers had high level of CK in the area of motion.
Generally however, I have found in this study teachers’ content knowledge and their beliefs about the learning and teaching of motion to be related without either being the determining influence in teachers’ responses to students.

Differences in feedback of the teachers who have high CK

Consideration of the last group suggests that both higher CK level and beliefs about the meaningful use of formulae in problem solving influence teacher feedback on student misconceptions. However, the nature of their beliefs matters, as illustrated by the example of Mr Peterson. In the first group of the teachers noted above, Mr Peterson’s CK was classified as being at a high level, but both his beliefs about teaching and learning motion and feedback were focussed on Disciplinary Thinking (representation). It appeared his high level of CK did not automatically dispose him to attend to Student Thinking about the discipline of motion in his feedback, and nor did his many years of teaching experience. He did not believe that students would have difficulty using and understanding graphs that ‘good’ physics teaching could not prevent. It should be noted that, he used several graphical representations, when explaining the formula $v = v_0 + at$.

His approach to meaningful problem solving was predetermined, as explained in Chapter 5, page 125.

6.6.2 Differences in feedback among teachers who gave dual attention to both Student Thinking and Disciplinary Thinking

A close analysis of teachers’ beliefs about teaching and learning motion tasks, in relation to their interpretations of, and feedback on all student responses provided insight into the thinking and reasoning of teachers whose feedback attended to both Student Thinking and Disciplinary Thinking. Dual attention to Student Thinking and Disciplinary Thinking is however not simply a characteristic of teachers with high content knowledge.

Two teachers (Ms Chick, Ms Johnson), who had high content knowledge, attended to both Student Thinking and Disciplinary Thinking in their responses to students difficulties providing a careful articulation of a well developed sequence of ideas. Their responses reflected their deep understanding of the content, and demonstrated their capacity to apply this knowledge and beliefs about problem solving and the use of formulae in ways that make those ideas meaningful and specific for students. For example, Ms Chick’s beliefs about teaching the application of formulae to problem
solving were expressed as skilled knowledge of the students’ development of individual understanding of the content and the process of problem solving in this area. This predisposed her to integrate both Student Thinking and Disciplinary Thinking to offer a logical justification of her argument, rather than superficial and general commentary, and provide specific feedback.

The feedback responses of the other six teachers who gave dual attention to Student Thinking and Disciplinary Thinking were not expressed as meaningful problem solving strategies and did not offer specific feedback. Amongst these teachers, two teachers had high CK and four teachers had low or medium CK levels. These are detailed and discussed below.

Although two other teachers (Mr Robinson and Ms Jenkins) had high CK, their content knowledge was not expressed in their feedback as meaningful and specific responses. Their beliefs about problem solving attended to mathematics aspects of the task, rather than attending to meaningful problem solving. For example, when providing feedback, Mr Robinson asked several systematic questions about problem solving strategies, but he did not use his high CK to provide specific questions that scaffolded meaningful problem solving. Although the assumption of this study was that teachers who attend to both Student Thinking and Disciplinary Thinking in their feedback, and have high CK, would promote meaningful student problem solving, it was interesting that this was not necessarily the case with these two teachers. The current study suggests a relationship between teacher dispositional knowledge or beliefs about teaching problem solving and the nature of their interpretations and feedback on student solution of motion task that may be more complex than has been assumed.

Four other teachers, who attended to both Student Thinking and Disciplinary Thinking, had a low or medium level of CK, and either their content knowledge or poor strategic thinking limited their feedback. For some, their strategic thinking about the teaching and learning of motion informed their feedback, but their low CK limited their ability to integrate ST and DT to provide a meaningful problem solving strategy. Mr Geraldton, Mr Richardson, and Mr Pierce fell into the first group, see section 6.6.1. The beliefs of these teachers referenced general pedagogical theory and formal Newtonian theory. However, their responses were not directed to “the development of qualitative understanding”; instead their feedback was concerned with the significance of “quantitative methods of representation and algebraic methods of solution” (Hobden,
1998, p. 229). Their feedback drew on general perceptions of Student Thinking and Disciplinary Thinking which they did not integrate in their feedback. Their feedback seemed to be directed to explaining how to get the right answer to a specific problem, not to supporting students’ ongoing learning. Teachers such as Mr Geraldton, who believed that students’ mastery of physics concepts in motion problem solving can be directly read from their test or exam results, spoke of the challenge for physics teachers to transmit the formal concepts to get the correct answer, rather than attending to understanding the physical relationships described in the task. Mr Jackson in his feedback, which attended to both Student Thinking and Disciplinary Thinking, used terms such as “visualizing”, “imagination” and “building understanding” (see 4.9). However, he did not provide task-specific advice to each student about how they could move forward, and used similar examples and feedback for different students. His beliefs about teaching the motion topic also showed that he focused on his own understanding of the motion topic, rather than responding to student misconceptions or views about the motion topic (see 5.3).

In short, my discussion of the differences in the feedback of the eight teachers who attended to both ST and DT related to the teachers’ employment of language generally, and more specifically to their reasoning about student needs and/or understandings of the formal physics concepts, where an understanding of the use of mathematical models was required.

To summarise, variations in teachers’ interpretations of, and feedback on student correct and incorrect solutions (section 6.2) suggested relationships between these two important elements of teaching practice. All teachers were also grouped based on the relationships between their beliefs about learning and teaching motion, their CK and their feedback to the incorrect solution to Bike task, discussed in 6.6.1, and 6.6.2. These findings suggest that the nature of teacher’s interpretations of, and feedback on student solutions often just as strongly reflected their beliefs about teaching and learning as their content knowledge in the area of motion. However, the findings also show that teachers’ representations and constructions vary with the nature (standard and non-standard) of the task.
Figure 6.1 schematically represents the dynamic relations between the entities in this study.

![Diagram of social constructionist representation](image)

**Figure 6.1:** A schematic social constructionist representation of the dynamic relation between a student’s incorrect solution, two forms of teacher knowledge and teacher interpretation and feedback in this study. An implied discourse concerned with promoting meaningful student problem solving.

N.B: R = Representation; C = Construction, T = Teacher; S = Student; CK = content knowledge

The implied discourse is the teacher’s internal conversation between the student’s construction of the teacher’s representation and the student’s representation of the teacher’s construction. TC is the teacher’s construction of student solution, TR is teacher feedback representing ‘tactics’ that they believe will be effective for the student SR is student representation of their thinking to the teacher and SC is the student construction of teacher’s feedback.

An individual teacher’s dispositional knowledge or beliefs and content knowledge interact to inform and are informed by the student’s attempted solution. A teacher’s professional identity can be studied in the reflective practice of interpretation and feedback involving the student and hopefully other teachers.


### 6.6.3 Teachers’ teaching across the types of motion tasks

With respect to the teachers’ beliefs about teaching and learning motion tasks, the tasks themselves influenced the teachers’ approaches. The teachers focused on procedural notions of solving and teaching the standard (Bike) task. With respect to the other standard task (Glider) some teachers attended to qualitative features. Others used a mathematical approach; that is using the symbols, and/or numbers, in order to obtain the correct answer. While some teachers used a qualitative approach to the Glider and Bike task which were both amenable to a mathematical solution and hence a formal grammatical presentation, in the non-standard (Shoved Block) task a qualitative and analysis and presentation of disciplinary content was required, and hence a non formal grammatical process of problem solving. No numerical values were stated in that problem and no axiomatic solution could be rehearsed.

While teachers’ interpretations and feedback with respect to the standard task emphasised both Student Thinking and Disciplinary Thinking categories, the non-standard task prompted most teachers to shift towards either a Student Thinking (constructivist response) or Disciplinary Thinking (representational) focus (see Table 5.22). Teacher distinctiveness emerged. The motion curriculum in Year 11-12 to which these teachers taught did not include the non-standard task. Physics teachers are not challenged and have few opportunities to rehearse heuristic or non-axiomatic uses of mathematical models.

### 6.6.4 Teachers’ teaching and their teaching experience

As explained in the previous chapter, the teachers’ experiences were classified according to the years they had been teaching, and all were current teachers of physics at senior high school level. It was interesting that most teachers (e.g. Mr Jackson, Mr Geraldton), who were unable to solve the non-standard task, were classified as having a low level of CK and yet were experienced teachers. This finding is consistent with the literature which suggests that some teachers who have taught for many years come to conform to a narrow reading of standard curriculum material and text book presentations. Consequently their subject matter knowledge is limited to the content found in textbooks and has not necessary developed. In this regards Gess-Newsome (1999) has stated that,
Teachers having low levels of subject matter knowledge often teach for factual knowledge, involve students in lessons primarily through low level questions, are bound to content and course structures found in textbooks, have difficulty identifying student misconceptions, and decrease student opportunities to freely explore the content either through manipulative or active discussion. (p.82)

With respect to diagnosis of the source of student error in solving the standard and non-standard motion task, the results of the teachers whose propositional knowledge was classified as being low level are consistent with this observation in the literature. For example, Mr Jackson frequently focused on the reality of the motion tasks or the accuracy of the solutions to the tasks used in the context of physics, when explaining his feedback or teaching the motion tasks. He was the only teacher who used the same words, when providing feedback on both the correct and incorrect student solutions to the standard task. His CK was classified as being at a low level, and the focus of his teaching limited the feedback he provided.

To summarise, compared to teacher beliefs about learning and teaching motion, years of teacher experience per se, was not strongly determinant of the nature of feedback they gave on student responses, but this relationship requires further study.

6.7 Summary

In the present study, a major finding of this study is that teachers’ interpretations and feedback on student solutions could be categorised in terms of the extent to which they attended to Student Thinking and Disciplinary Thinking. The findings showed that, in this sample of physic teachers, there may be a possible relationships between the teachers’ feedback to students’ difficulties and two forms of teacher knowledge - that is propositional content knowledge forms, and dispositional knowledge or beliefs about teaching- learning motion. The nature of their feedback to student difficulties were more strongly associated with the nature of teachers’ beliefs about teaching and learning motion, than with their level of propositional knowledge, or their teaching experience.

The teachers’ beliefs were inferred from their reasoning in a familiar and non-familiar context. This study did not have a linguistic focus, although the study analyses the discursive intent in teacher written and oral language. It needs to be noted that all teachers were native English speakers and were familiar with the English used, when
responding to the questionnaire and interview items. As an English Second Language (ESL) speaker I sought and obtained considerable assistance in decoding the texts in this study. My interpretations of the teachers’ responses and comments were conducted in consultation and discussion with four experts in the science and mathematics fields and an expert in the language education field who are acknowledged at the beginning of the thesis. It should be noted that the responses of these teachers in the questionnaire alone were sometimes insufficient, but the follow up interviews provided additional insights and revealed more of their understandings and the range of strategies used. There were more items on the questionnaire than the items reported here. Qualitative research, as any number of authorities have remarked, is a messy business, and the analysis of the Physics teachers’ skilled knowledge and intent over 20 months was certainly laborious but fully engaging.
Chapter 7: Conclusions

7.1 Introduction

This study was conducted with eleven upper secondary school physics teachers in the Australian state of Victoria. The teachers’ written and oral language was studied to describe and analyse their agency and intentions when providing feedback on student solutions to linear motion tasks. The analysis references aspects of teacher knowledge.

In several areas of science education, the results of previous studies on teachers’ "pedagogical content knowledge” claim different relationships between teachers’ knowledge and beliefs and the feedback they construct. There is a body of literature, discussed in Chapter 2, about difficulties experienced by students when studying motion, in conventional problem solving settings. This literature points to the significance of a better understanding of the teacher’s strategic thinking. This study examined upper secondary school physics teacher’s interpretations of, and feedback on, student solutions to linear motion tasks. These two concerns prompted me to conduct this study with the aim of addressing two questions that had occurred together in my own experience in teaching physics. It was interesting to ask why my students (in both the Iranian and Australian contexts) seem to have similar difficulties solving motion tasks, and more importantly to ask how students are guided by teachers to develop the capacity to solve motion tasks. This study was designed to address two main research questions:

1- How do high school physics teachers interpret correct and incorrect student solutions to standard textbook and incorrect student solutions to non-standard motion tasks in physics, and on student explanations of the physics formulae?

2- How do high school physics teachers provide feedback on correct and incorrect student solutions to standard textbook and incorrect student solutions to non-standard motion tasks in physics, and on student explanations of the physics formulae?

To obtain an in-depth understanding of teacher interpretations of, and feedback on, student responses, a qualitative approach incorporating a case study design was chosen. I used two different data sources: a Problem Centred Questionnaire (PCQ) and a Problem Centred Interview (PCI). These involved standard and non-standard motion tasks to assess the responses and beliefs of the eleven upper secondary school physics
teachers, and to address the research questions. Some significant components of teacher knowledge were explored using the PCQ and PCI. These components comprised the teachers’ interpretations of the hypothetical student solutions, their beliefs about teaching approaches and the learning of motion, and their CK level, as well as their feedback on student difficulties in the linear motion topic, which is the focus of the study. In this chapter the major findings, some personal reflection on research into the nature of physics teaching, as well as the limitations and implications of the study are discussed.

7.2 Major findings and conclusions

A major finding of this study is that teachers’ interpretations and feedback on student responses could be categorised in terms of the extent of their dual attention to Student Thinking and Disciplinary Thinking. With respect to different motion tasks and various student solutions, teachers’ interpretations of, and feedback on student solutions are a dynamic ‘conversation’ between Student Thinking and Disciplinary Thinking. The major findings are organised based on three areas which were relevant to the aim of this study: examination of the differences in feedback among teachers who focused on both Student Thinking and Disciplinary Thinking, relationships between teacher feedback and aspects of teacher knowledges, and variation in teachers’ knowledges.

Examining of the differences in feedback among teachers who focused on both Student Thinking and Disciplinary Thinking:

As some teachers attended to student needs and formal physics concepts, it was found that their strategic dispositional knowledge or beliefs about making a problem solving task meaningful, were reflected in their use of feedback and their high level content knowledge. These teachers provided specific feedback to student difficulties. However, some other teachers with high content knowledge, who attended to student needs and formal physics concepts, did not provide strategic meaningful problem solving feedback. They attended predominantly to demonstrating axiomatic mathematical truths illustrated in the task, rather than qualitative aspects of the problem. The complex appreciation of the strategic pedagogical use of mathematical models in physics teaching is highlighted. Among those teachers who attended to both Student Thinking and Disciplinary Thinking, but had a low or medium level of CK, attempts at
meaningful, specific feedback were limited either by their content knowledge or their strategic understanding.

The findings suggest the initial assumption in the current study and most other studies, that a high level of teacher content knowledge and a concurrent attention to both ‘student thinking’ and ‘disciplinary thinking’ would allow physics teachers to provide meaningful and specific feedback, maybe simplistic.

This finding shed light on the interdependent nature of two aspects of teacher knowledge – dispositional and propositional - in attending to student thinking and disciplinary thinking, in the interpretation of student solutions and the provision of feedback. These findings point to the need to reach a deeper understanding of teacher’s personal skilled knowledge which may be accessed through a fine grained analysis of their discursive practice.

Relationships between teacher feedback and teacher knowledges:

The findings indicate that the relationships between a teacher’s feedback and their content or propositional knowledge, dispositional knowledge or beliefs about teaching and learning motion, and their interpretations of student difficulties in specific tasks are more complex than the literature reviewed had suggested. In this study a pattern in the relationships between the above components of teacher pedagogical knowledge and their feedback was explored. This relationship is illustrated in the schematic representation of the iterative interactions of the components of the teacher’s pedagogical content knowledge involved in teaching problem solving (Figure 6.1). Although the elements were embedded in Shulman’s formulation of teachers’ PCK and were expected, the differentiation of each teacher’s thinking or intentions for teaching and providing feedback and the context of each problem task is preserved in this study of each teacher’s explicit and implicit language use or intent.

It was found that the nature of a particular teachers’ feedback to student responses was more strongly associated with the nature of their dispositional knowledge or beliefs, than with their level of formal training or propositional knowledge, or their teaching experience in years.
Chapter 7: Conclusions

Variation in teachers’ knowledges:

A unique feature of the research design was the use of surrogate student solutions, which permitted a comparison between teachers on the same student text. It was shown that the focus of individual teacher feedback on student solutions varied based on the type of task and solution. This suggests that each teacher’s pedagogical content knowledge is dynamic and responsive to different teaching situations. Although this is embedded in the idea of teacher PCK, which embraces both content knowledge and dispositional knowledge or beliefs, and was expected, the reported data provided specific examples of teachers’ knowledge and their reasoning in representing formal physics concepts and responding to student thoughts/views.

Even where the teachers had a similar focus on the student’s solution or on explaining the formula, the nature or detail of their comments differed. While these differences were not surprising, the accounts of each teacher succeeded in distinguishing their different pedagogical content knowledge in the area of physics teaching being examined.

7.3 Personal reflection on the nature of physics learning and teaching

I have always believed that the science of physics, in both its experimental and theoretical wings, should be admired as one of the great human achievements. In real life situations, this scientific knowledge has an important role. There are clear parallels between the ontological processes in knowledge development in physics and my thinking about the development of student understanding in ongoing conversations with their physics teacher.

The current study is an exploration of physics teachers’ intentions in teaching problem solving in linear motion. In order to get our accounts of physics teaching right, we must pay attention to two important aspects: (a) the nature of the motion problem, and (b) teaching and curriculum. First, motion problems involve mathematics and real life situations in which the language games of physics teachers are important for teaching and learning motion concepts. As stated by Nashon, Anderson, and Nielsen (2009), becoming a qualified physics teacher needs an understanding “of the connections between physics and mathematics” (p. 5). These researchers believed that,

We see this linkage as an important objective for instructional planning:
helping students to build substantive understanding across subject areas,
freely utilizing different ways of knowing to deepen and broaden conceptual knowledge structures. This is the pedagogy that was being modeled through the problem solving task, and physics instructors should where possible, utilize math content with which the students are already familiar, thereby reducing cognitive overload. Also it is important to minimize unnecessary mathematics noise, even when it is familiar to the students.(p.15)

Teachers’ use of mathematics is heavily implicated in this pursuit. This is a very different matter from studying the formal properties of the disciplinary discourse of physicists who take the foundations of mathematics as a model for the philosophy of physics and physics teaching. In a representational use of a mathematical technique every concept employed, for example, \( v = u + at \) in the mathematical analysis of linear motion, can be shown to have physical meaning. However there are the auxiliary uses of mathematics, which see a natural reading of the mathematics as a description of a possible mechanism. In addition, the mathematical treatment involves strictly heuristic concepts other than those which are defined immediately in the phenomena and has no physical meaning.

Second, with respect to teaching and curriculum, in relating the subject matter of a scientific discourse – here on Newtonian linear motion – to human experience and human techniques of investigation, the teacher uses an apodeictic or demonstrative discourse about a ‘possible world’ of taxonomic principles and definitions. “The laws of classical kinematics are strict derivative from the apodeictic principle of uniform acceleration as the second derivative of space with respect to time. This is what uniform acceleration is in kinematics” (Harré, 1990, p. 380).

A feature of this study that has not been previously systematically observed is the exploration of teachers’ dispositions or beliefs about motion principles as laws. The study also explores the teacher’s discourse that refers to the mechanisms of problem solving, which brings about the regularities that teachers describe as they teach linear motion. It has also been observed that teachers attend to the marginal cases (such as correction of units, and answers ...) that do not provoke any serious revision of the laws. On the contrary, the discourse about friction occurring in a real-life situation (as seen in the Shoved Block task) is accommodated in further laws which are empirical, inductive, and depend on displacement of concepts in teachers’ thinking. This suggests that the
physics curriculum cover this type of task to improve and cultivate the required skills to address the difficulties of students in different motion tasks. These kinds of skills may be achieved by giving sufficient attention in the physics curriculum to perspicuous examples from the everyday world of the students. The problem solving tasks used in this research were devised as perspicuous examples that may act as a hinge on which the doors of life turn (Wittgenstein, 1975), a hinge between conversational realities and disciplinary discourses. In the lived world of physics teaching, such tasks provide affordances not only for the student but also for research into the social construction of meaning for physics teachers.

Such an exploration of what teachers do in attempting to induct students into the grammatical world of physics could be framed in the following question: How did the different physics teachers in this study use mathematical expressions in their teaching of linear motion in the two types of tasks, standard and non-standard?

7.4 Limitations of the study

There are a number of obvious limitations that flow from the design of this study and should be acknowledged. The sample for this study, eleven upper secondary physics teachers, was far too small to permit generalizations to other groups of physics teachers or to other educational systems. It was not the intention of this study to furnish quantitatively generalizable results about the likely responses of other upper secondary teachers. The applicability of the findings in other contexts is something that readers must determine for themselves.

It should also be noted that the questionnaire and interview approach employed here does not provide legitimate evidence for what teachers may do in a real-life teaching situation in response to situations they have more control over and with students they know. Furthermore, the absence of a strategy or explanation in a teacher’s response does not necessarily imply that such a strategy is not part of their teaching beliefs and intentions in other contexts. The use of hypothetical student responses may be thought to have limited the potential discourse between teacher and student.

The tasks used in the PCQ and PCI demonstrated only some possible student difficulties. However, there was a need to include a variety of student responses/difficulties in linear motion tasks in the interview and questionnaire items, in
order to obtain a clear picture of teacher intentions and beliefs about teaching and providing feedback. All of these limitations await further research.

### 7.5 Implications for teacher training

As a considerable number of these physics teachers demonstrated a low level of competency in solving the non-standard (non-axiomatic) task, one recommendation for teacher educators, both in initial degree courses and in teacher education in the field, is to focus on a conceptual approach to solving problems, particularly in the linear motion topic. The case study materials in this thesis may be useful for those curricularists in research, schools and elsewhere attempting to create or teach to a physics curriculum which improves pre-service teachers’ competency in constructing and teaching meaningful problem solving strategies. Non-standard tasks may be useful tools in this endeavour.

It has been shown that teacher skill in discussing the use of motion formulae in the physics context is explicitly shown to be an important issue (Sherin, 2001). This to a large degree should define teachers’ thinking about constructing good physics teaching practice, particularly, their feedback on student difficulties in the standard linear motion task. Commitment to teaching meaningful problem solving and understanding of the use of kinematics formulae in linear motion is important.

The world of teaching and learning including physics education is not just a long sequence of reliable regularities. In the philosophy of physics teacher education the “fallacy of actualism” or demonstrating the proof may have been correctly identified but often does not go far enough in substituting dispositional for phenomenal concepts and what is often missed is the key question of the proper location of causal powers in plausible powerful particulars. Depriving human beings, either students or teachers, of their causal role presents a picture of the world of physics in which people are driven this way and that by extra-personal forces only. Physics education should be taught as a genuine project of human emancipation. Students and teachers could then realise that they are people and so active agents trying to realize their projects with others. The constraints that society seems to place upon their pursuit of understanding motion are grammatical. The story-lines and conventions in accordance with which teachers and students live could be different and new grammars could be created and adopted. Developing pre-service teachers’ commitment and beliefs about teaching meaningful
problem solving and choosing appropriate tasks in linear motion should be a focus of teacher educators in their physics instructional planning. For instance, teacher educators need to investigate and identify pre-service teachers’ beliefs about the use of mathematics, such as kinematics formulae or graphs in physics, and discuss this important notion in relation not only to the motion topic but to a philosophy of physics.

An investigation of discursive practices used to teach motion problem solving in physics was not the central theme of my research. However, the argument presented in this study recognises the need in practice and research to consider how educators might better examine and critically reflect upon communicative language teaching and pre-service teachers’ reasoning in classroom discourse in the area of feedback to high school students.

7.6 Implications for studies of teacher PCK

This research synthesises previous research, by drawing together the constructivist views of conceptual change in the teaching and learning of science (e.g. Duit, Niedderer & Schecker, 2007) and some of the literature about problem solving (e.g. Redish, 1994; Sherin, 2001; Tuminaro, 2004). Together these have implications for exploring teacher beliefs and intentions when teaching motion. A study of teacher intentions provides access to descriptions of the relationships between the two key components of teacher knowledge; that is, dispositional knowledge or beliefs and propositional knowledge or content knowledge. This study sought a situated description of teachers’ pedagogical knowledge, in which problem solving is seen as a core learning outcome, as well as a teaching strategy.

7.7 Methodological implications for further research

This study has developed a framework for exploring some aspects of physics teachers’ knowledge in the motion topic through using an approach explained in Chapter 4. It appears from initial explorations that the questionnaire and interview have the capacity to reveal subtle differences between teachers’ responses, and these might be attributable to differences in teachers’ PCK. 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.
Both a description and many characteristics of Student Thinking and Disciplinary Thinking categories were provided, with respect to the teacher interpretations of, and feedback on student responses to the linear motion tasks. This could be used as a diagnostic tool or analytical template, as a guide for instructional intervention, as a guide for curriculum development, or be used in further research to interpret and examine teacher beliefs with respect to their interpretation and feedback on student responses in other topics in the context of physics.

**Further Research into Physics Teaching Through Problem Solving**

This study unlike many of those reviewed is a psychological investigation of a common transaction, that of problem solving, in physics teaching. Research into physics teachers’ skilled knowledge in scaffolding meaningful problem solving will be an important topic in education, particularly in providing feedback on student difficulties in specific linear motion tasks.

There are tensions between realist and social constructionist missions in meeting the responsibilities of physics teaching. It is one thing for researchers to point to the teacher accountability and responsibilities entailed in responding to student difficulties, and to say that teachers should not undermine the very relations upon which the force of their own content knowledge rests; it is quite another to develop standards which allow teachers and others to judge between communicative practices. This study is but a small step in this direction. Shulman’s Pedagogical Content Knowledge cannot refer only to what knowledge teachers share, it must also refer to the judgements shared. Physics teachers and their students communicate their knowledge of physics, but what do they begin with? There are two answers that span a territory that science education research, including the current study, is only beginning to explore. One answer is in the territory of neuroscience; that is, students and teachers begin with genetic and neurophysiological enabling conditions or capacities. Another answer is that they begin with ‘experiences’ or affordances – knowledge gained in skilled or intentional interaction with written text and other entities – in the sense of symbolic productions. A performance is skilled if it is intentional, that is directed to some end and is subject to assessments of right or wrong; that is, it is normatively constrained by what counts as correct in the perceptions of the community of physicists and physics teachers. Wittgenstein, Vygotsky and Harré have all suggested that a useful model for the interpersonal flow of skilled action is conversation. Teaching and learning physics is a
conversation. The current study has been designed to focus on teaching-learning activity and process of problem solving – an implied dialogical transaction between student and teacher around a task designed for the purpose. The social semioses are purposefully limited by the task. For the constructivists, reviewed above, who can very roughly be characterized as focused on ‘words in their speaking’ rather than ‘words already spoken’; that is, exhibitions rather than outcomes of learning (McDonald, 1992), problem solving has a primarily rhetorical-responsive function in which the representational-referential function of naming-labelling in the transaction has a secondary and derived function. Social utterances, rather than sentences with their individuality and monologic creativity, were the basic units of analysis. In making the actual utterances studied here, both student and teacher had to take into account the already linguistically shaped context of the problem task into which they were directed. Any concrete utterance is a link in the chain of this particular speech transaction in which an appropriate problem functions as a Wittgensteinian ‘hinge’ that is designed to open a door between disciplinary discourses and conversational realities for both teacher and student (Shotter, 1995). The action of teaching and learning through problem solving is psychological since it is intentional – the teacher and student are trying to accomplish an understanding of aspects of linear motion – and it is normative – the performance is subject to a variety of standards of conceptual acquisition but also deployment. Enabling conditions do not only include the neural state or preconceptions of teacher and students, but there are also environmental conditions like an appropriate problem-task that must be introduced for a skilled performance to be possible. Just as one cannot judge or display skills as a mountaineer unless there is a rockface or artificial surrogate to climb, the teacher and student cannot judge or exhibit a skilled performance in problem solving unless appropriate problem tasks are attempted. Different problems afford each their own range of possible actions. The written texts of the problem task are both material and discursive entities with complex and shifting criteria of identity. They can be addressed as rhetorical depictions of physical phenomena or events in an interrogative mode, as word games for detecting or developing certain paradigmic habits of mind, or as invitations to thought experiments in which possible cause and effect relations can be internally rehearsed and public epistemological claims framed. Each problem is pregnant with templates for error, sensory qualities of what each student and teacher perceives, does or says.
Chapter 7: Conclusions

The very idea of a skilled performance by a student requires the teacher to take account of the social conditions under which their performance or that of the student is assessed. The criteria of such assessments are immanent in the physics education discourse, impoverished as it often is in schools, only becoming overt when a student has to be corrected when training is going on, or examined. The problem skills may be picked up with overt training and normatively constrained without overt judgements of correctness being offered. The standards may be embodied in the responses of expert others. Sometimes these are embodied in textbook manuals. (see Halliday et.al, 1994 Chapter 2 for an excellent example). A dual ontology is studied in problem solving, it is something people do, a symbolic/discursive performance, but the prior learning enabling conditions, or the material affordances which are characteristic of the problem, are essential for the students and the teacher to bring off the performance.

Vygotsky (1986) suggested that the affective attitude which provides the thoughts and ideas of an individual with their dynamics, their particular motives, and dispositions, linking them to each other and their context in a particular way is a transmuted version of a social relationship, of an “instructional’ kind. The students come to instruct themselves as others instruct them. They ‘point things out to us’ (“Look at this!”); ‘change our perspective’ (“Look at it like this”); ‘order our actions (“Look at the model first, then at the problem data”); ‘shape’ our actions (“use a different equation, then it might fit”); ‘remind us’ (Think what you did last time, what do you already know that is relevant”; ‘encourage us’ (Try again’); make us ‘check’ our solutions (“Is that right?” “What have others found?” , “What makes you believe that?”) and so on for other functions. These are the means Vygotsky (1986) has in mind when he said that,

the main question about the process of concept formation – or about any
goal-directed activity - is the question of the means by which the
operation is accomplished … To explain the higher forms of human
behaviour, we must uncover the means by which man learns to organize
and direct his behaviour. (p. 102)

He concluded, “learning to direct one’s own mental processes with the aid of words or signs, is an integral part of process of concept formation” (ibid p. 108). In other words what the student in this study has learned to do in thinking conceptually, is, in Vygotsky’s terms, not to compare the configuration of a supposed mental representation with the configuration of a particular state of affairs in reality, but to organize and
assemble in a socially intelligible way, in a way which makes sense to significant others, bits and pieces of dispersed information in accordance with ‘instructions’ they provided, and which now a supposed ‘concept’ provides.

In this view, rather than a self-contained, simply subjective activity within an individual – dealing with merely inner, cognitive ‘pictures’ which may or may not be accurate representations of an outer reality – thinking conceptually becomes a special social practice. The mathematical moves in solving a physics problem in linear motion posed in standard ‘grammatical pictures’ which ‘literalize’ metaphors (Edwards, 1982), or models are perfectly benign, as long as the phenomena being dealt with are orderly, and the problem is just to find the form of their order; they allow the student to act – to find the solution – indeed they channel the student (as individuals) into acting – in a way which conforms to that order ahead of time. In the research literature reviewed there is a common critical belief that in physics teaching a proposition is illustrated in a few standard examples, and then pre-supposed as understood in full generality. While the research reviewed seems to assume that physics teaching should attempt to show how things, in the broadest possible sense of the term, hang together, there is a major challenge here that is not adequately addressed. It is Wittgenstein’s point: when the phenomena of interest to the student are not already orderly, when they are – as in everyday applications – somewhat chaotic, or only partially ordered, the students will encounter difficulties. Wittgenstein (1980) investigated the consequences of such ‘bewitchments’. This study explored student difficulties and teacher responses in both standard and non-standard problems. How else should teachers proceed, if not in terms of ‘grammatical pictures’ or models? Wittgenstein’s answer is in terms of ‘perspicuous representations’, a way of making sense of things that students are unable to do on their own, a way that relies upon them ‘seeing’ things in the same way as the teacher as significant other.

Another extension of this current research could be to explore the use a larger range of standard and non-standard motion tasks with a view to developing a language of use that goes beyond saying, “this one works” and “this one is too hard”. These tasks could be varied in terms of having mathematical formulae/ using graphs in the linear motion topic. This would provide a more complete understanding of the effect of the problem type on teacher responses to student difficulties.
REFERENCES


References


References


