

**Improving Secondary Students' Revision of Physics Concepts
through Computer-mediated Peer Discussion and
Prescriptive Tutoring**

This dissertation is submitted for the degree of Doctor of Philosophy

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14th May 2010

Declaration of Originality

I hereby declare that my thesis/dissertation entitled:

Improving Secondary Students' Revision of Physics Concepts through Computer-mediated Peer Discussion and Prescriptive Tutoring

- *Is the result of my own work and includes nothing which is the outcome of work done in collaboration except as declared in the Preface and specified in the text*
- *Is not substantially the same as any that I have submitted, or, is being concurrently submitted for a degree or diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in the Preface and specified in the text. I further state that no substantial part of my dissertation has already been submitted, or, is being concurrently submitted for any such degree, diploma or other qualification at the University of Cambridge or any other University of similar institution except as declared in the Preface and specified in the text*
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I have also:

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Undertaking research work of any kind is never an easy endeavour, and research work that is tied to a PhD is no exception. For me, the successful completion of the research study reported in this dissertation literally involved blood, sweat, and tears, although a substantial portion of those were not mine. For that, I am indebted to all who had partaken in this journey with me, helping and supporting me along the way.

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Summary of the Study: Improving Secondary Students' Revision of Physics Concepts through Computer-mediated Peer Discussion and Prescriptive Tutoring

In this dissertation, I report on the design, implementation, and evaluation of my intervention for the revision of physics in a mainstream public secondary school in Singapore. This intervention was conducted over a one-year period, and involved students who were taking their GCE 'O' level physics examination after immersion in the intervention, which was conducted as part of their regular physics revision curriculum. Based on sociocultural theory, the intervention changed the practice of how physics revision was conducted in a particular secondary physics classroom. The intervention consisted of a computer-mediated collaborative problem-solving (CMCPS) component and a teacher-led prescriptive tutoring (PT) component. The CMCPS portion of the intervention required the students to follow basic "ground rules" for computer-mediated problem-solving of physics questions with other students, while the PT portion saw the teacher prescriptively addressing students' misconceptions, misunderstandings, and other problem-solving difficulties as captured by the discussion logs during the CMCPS session. The intervention was evaluated in two stages. First, a small-scale (pilot) study which utilised a control group (CG) / alternate intervention group (AG) / experimental group (XG) with pre- and post-test research design was conducted in order to evaluate whether the intervention was effective in promoting improved learning outcomes of a small group of students. Given the success of the pilot study, a main study involving the entire class of students was conducted. This main study was evaluated by comparing the cohort's actual GCE 'O' level physics results with their expected grades (as given by the Singapore Ministry of Education based on the students' primary school's results). Also, the students' 'O' level physics results were compared with the average physics results obtained by previous cohorts. The quantitative data indicated that the intervention for physics revision appears to be effective in helping the entire class of students revise physics concepts, resulting in improved test scores, while the qualitative data indicated that the students' interest in physics had increased over time. The physics teacher also reflected that the intervention had provided her with much deeper insights into her students' mental models.

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List of Selected Publications

Peer-reviewed journals:

Soong, B. & Mercer, N. (in press). Improving students' revision of physics concepts through ICT-based co-construction and prescriptive tutoring. *International Journal of Science Education*.

Soong, B., Mercer, N., & Er, S. (2010). Revision by means of computer-mediated peer discussion. *Physics Education*, 45(3), 264-269.

Soong, B. (2008). Learning through computers: uncovering students' thought processes while solving physics problems. *Australasian Journal of Educational Technology*, 24(5), 592-610.

Peer-reviewed conferences:

Soong, B., Mercer, N., & Er, S. (2009). Students' difficulties when solving physics problems: results from an ICT-infused revision intervention. *Proceedings of the 17th International Conference on Computers in Education*, 361-365.

Soong, B. & Mercer, N. (2009). Using ICT to improve students' revision of physics concepts through co-construction and prescriptive tutoring: results of a pilot study. *Proceedings of the World Conference on Educational Multimedia, Hypermedia & Telecommunications*, 1180-1189.

Invited book chapters:

Soong, B. (2009). Gleaning practical knowledge insights from problem-solving dialogues. In S. Kan (Ed.), *Knowledge Management: Singapore Perspectives 2009*. Singapore: Information and Knowledge Management Society, 55-66.

Soong, B. (2008). Educational technology and the "no significant difference" phenomenon. In S. Kan (Ed.), *Knowledge Management: Singapore Perspectives 2008*. Singapore: Information and Knowledge Management Society, 20-36.

CHAPTER ONE

INTRODUCTION AND BACKGROUND

I start this chapter by providing a discussion on the purpose of educational research. I illustrate that different educational researchers ascribe different goals to their research endeavours, and explain that my personal belief and objectives for conducting educational research stem from my historical sociocultural interactions with innovative educational practices (both as a recipient as well as a contributor). Next, drawing data from the UK and Singapore, I highlight the need for research to address secondary physics education, emphasising the need for improving pedagogical practices in physics classrooms. Thereafter, I provide a discussion on the use of computers in education for physics teaching and learning purposes, and attend to claims that computers cause no significant differences in learning outcomes. I then explicate my overarching research intentions and state my epistemological grounding and theoretical perspective which serve as the lenses through which I view my research work. Finally, I conclude this chapter by providing an overview of the structure of the dissertation.

1.1 The Purpose of Educational Research

1.1.1 Goals of Educational Research

In educational research, there is a vast diversity of educational themes that researchers are interested in. In addition to the diversity of educational themes and the widely accepted view that in educational research there is “no canon, there are no core methods” (Schoenfeld, 1999, p.167), there are also divergent views on the goals of educational research. For example, Moll and Diaz (1987) proclaimed categorically that the goal of educational research is to “produce educational change” (p. 311) and for Pring (2000), “[w]ith few exceptions, the classroom, and the transaction between teacher and learner in all its complexity, are what research should shed light upon” (p. 26). Additionally, Hargreaves (1997) argued that “[e]ducational research could and should have much more relevance for, and impact on, the professional practice of

teachers than it now has" (p. 405) while for Mortimore (1999), the main purpose of "educational research is to further educational improvement" (p. 9). However, for Hammersley (2003), "research, even practical research in the field of education, should always aim at being informative rather than educative" (p. 19) and for Badley (2003), the pragmatists (himself included) "see research as only offering a 'modest practical contribution' to educational practice" (p.304). Therefore, it appears that educational research crosses different subject domains and invokes different methodologies and methods, and involves polar opposite end-goals (being tied to, or divorced from, practice; see also Clark, 2005; Oancea, 2005; Whitty, 2006). For a researcher who must decide on a path and walk down the direction selected, how should one choose?

1.1.2 Personal Belief and Objective for Conducting Educational Research

In Antoine de Saint-Exupéry's *The Little Prince*, the fox explained to the Little Prince that, "It is the time you have wasted for your rose that makes your rose so important". In other words, certain objects, people, and even beliefs are important to us because of our deep sociocultural history with it. For me, my 'roses' are computers and education, and the time I have 'wasted for' them includes the thousands of hours spent designing, implementing and evaluating computer-based learning interventions (e.g. Soong, 2001) and writing educational books (e.g. Soong, 2006) that I hope would help students learn better. Reflecting back on my yester-years, it is clear to me that it is my direct experience of learning in innovative learning environments and reading of inspiring educational books that have made a significant difference in my life. Hence, it is my belief that there are better ways of teaching and learning, and my motivation is to provide students with a similar experience so that they may be enriched by innovative educational practices, just as I have. Therefore, it follows that the educational research work I conduct should be tied closely with educational practices, focusing on improving them so as to help students learn better. For me, educational research is tied to practice, and the research work described in this dissertation is a reflection of that belief.

1.2 The Need for Research to Address Secondary Physics Education

Physics education is in crisis (Zhang & Fuller, 1998; Tseitlin & Galili, 2005; Price, 2006; Cornell, 2010). For more than a decade, the number of students reading physics has been in decline. As early as in 1994, Woolnough reported that in "many countries there is a decline in the number of students wishing to continue with physics" (1994, p.368). Almost a decade later, Williams et al. (2003) reiterated that we "need no reminders that too few students elect to study physics at A-level, and subsequently, as undergraduates" (p.324). Based on statistics published by Cambridge Assessment comparing students' uptake of GCSE subjects in 2000 and 2006 (see Rodeiro, 2007, p.12), it was found that physics was the least taken up core subject in the year 2000, and this situation remained the same in 2006. In addition, analysis of data provided by the Joint Council for Qualifications (JCQ, 2007; JCQ, 2008; JCQ, 2009) revealed that in 2007, 2008, and 2009, physics still remained as the least taken up core subject among UK secondary school students for the GCSE examinations (I excluded from my analysis the combined sciences, since curriculum changes made in 2007, 2008, and 2009 did not allow me to compare like with like). This sharp decline in students opting to read physics is similar in Singapore. In a recent Straits Times (Singapore's main newspaper) article entitled *Why S'pore needs more people to study physics*, Professor Pao Chuen Lui (the former Chief Defence Scientist of Singapore) warned that,

...there are dark clouds in the sky. The enrolment in physics in junior colleges has declined from 80 per cent in 2000 to about 40 per cent today. Something must be done soon to reverse this, or it will have serious consequences for our nation's economic development in all technology-related sectors, as well as other equally serious consequences for the nation's capabilities in key areas such as defence and education. (as cited in Gunasingham, 2009, p. D10)

There are both macro and micro reasons for this decline. From a macro perspective, Woolnough (1994) identified factors such as home background and job attractiveness as key factors influencing whether students choose to continue reading physics. Interestingly, both

these factors were also identified by Lui as factors contributing to the decline of students reading physics in Singapore, as he explained that “[p]arents also play an important role. There is a misconception among some parents about the career prospects for physics graduates” (as cited in Gunasingham, 2009, p. D10).

From a micro perspective, Williams et al. (2003) found that the predominant reasons offered by UK students are that they perceive physics to be a difficult/hard subject and they generally do not enjoy the subject. These results are in-line with the findings of Smithers (2006), who related that “Physics [is] in [a] downward spiral as pupils think it is too difficult” (p. 11). Also, Sillitto and MacKinnon (2000) reported that “Physics has an image of being both 'difficult' and 'boring'” (p. 325). Similar views were echoed by Lui, who found,

...that there was a perception among students that the subject [physics] was difficult to grasp conceptually, as well as one that was difficult to do well in during exams. Another reason identified was that teaching methods used may not be interesting, resulting in more students dropping physics through upper secondary, junior college and university. (as cited in Gunasingham, 2009, p. D10)

In order to increase the uptake of physics by students, one key area identified by researchers is in improving the teaching and learning of the subject (e.g. see Woolnough, 1994; Barak & Shakhman, 2008; Gunasingham, 2009; see also Ogborn, 2004 and Cahyadi, 2007). Osborne and Hennessy (2003) highlighted the potential role of information communications technology (ICT) in transforming the teaching and learning of science in classrooms, while Price (2006) identified that computer games can “rescue...[the] crisis in physics education” (p. 1). In fact, there is overwhelming research on the various uses of ICT in science classrooms aimed at improving the teaching and learning of physics. For example, Christian and Belloni (2001; 2004; see also Novak et al., 1999; Belloni et al., 2006) provides a discussion on how web-based physics java applets (called physlets) may be used by teachers in order to help students

better understand various physics phenomenon by way of animations and visualizations of multiple representations. On a similar track, Sing and Chew (2009) described the positive outcomes they obtained when primary school students used web-based interactive learning objects for science learning purposes (see also UCeL, 2009, MERLOT, 2009, and CAREO, 2009 to gauge the extensiveness of such web-based learning objects). Besides web-based learning objects, ICT has also been used in physics classrooms as a tutor (e.g. Gertner & VanLehn, 2000; VanLehn et al., 2005), as a laboratory data logger and visualiser (e.g. Trumper & Gelbman, 2000; Thornton & Sokoloff, 1998), as a student response system (e.g. Duncan, 2005; Caldwell, 2007), as a virtual laboratory (e.g. Crosier et al., 2002), as a source of animated presentations (e.g. Kablan & Erden, 2008), as a homework delivery and grading system (e.g. Roth, Ivanchenko & Record, 2008) and as a means to encourage “epistemic interactions” between students (e.g. Baker et al., 2001, p. 89), amongst many others. However, do computers really lead to better educational practices and bring about significant improvements in learning outcomes?

1.3 Computers and the “No Significant Difference” (NSD) Phenomenon

Since the introduction of the printing press by Johann Gutenberg in the fifteenth century, technology has been looked upon as an agent of change (e.g. see Eisenstein, 1980). Looking specifically at technologies introduced into education in the last century, namely, film, radio, television, and more recently, computers, several influential people have made spectacular claims about their transformative effects. For instance, Cuban (1986, p.9) cited Thomas Edison as saying in 1922, “I believe that the motion picture is destined to revolutionise our educational system and that in a few years it will supplant largely, if not entirely, the use of textbooks”. More recently, Seymour Papert (1984) made a similar claim, predicting that “there won't be schools in the future....I think the computer will blow up the school...” (p.38). However, as Cuban (1986) pointed out, “Radio, film, language laboratories, programmed learning machines, computer assisted-instruction, use of typewriters in the elementary grades—all have been promoted as revolutionizing instruction yet today seldom appear in most classrooms” (p. 54). And after more than a decade of further research, he added, “When it

comes to higher teacher and student productivity and a transformation in teaching and learning...there is little ambiguity. Both must be tagged as failures. Computers have been oversold and underused, at least for now" (Cuban, 2001, p.179).

Cuban's observation that the reality of the transformative effects of technology in schools is falling way short of expectations is confirmed and extended by Russell (2001). Russell evaluated 355 research reports, summaries and papers involving different distance learning technologies and found "*no significant difference* (NSD) in student outcomes between alternate modes of education delivery" (p.1, emphasis in original).

However, many researchers disagree with the picture painted by Cuban and Russell. Ramage (2001) questioned Russell's methods of analysing his data, suggesting that Russell may have obtained his NSD findings because he "focused primarily on differences in the media rather than the methods employed *via* the medium" (p.1, emphasis in original) when Clark (1983, 1994) had established that media itself will not influence learning outcomes. In a rebuttal to Cuban, Becker and Ravitz (2001) drew on their own research involving over 4,100 teachers in over 1,100 schools across the USA to conclude that,

...computers are quite likely to take on greater importance in schoolbased learning within the next 10 years...Their exponentially increasing capacities, combined with smaller size, simpler networking, more powerful software, and their clear relevance to a constructivist approach to teaching make it very likely that computers will become as central to academic education in K-12 settings as they are essential to the productive lives of adults and college students today...such a future is, in fact, more likely than the one which Cuban foresees.
(p.14)

In my view, reality lies between the NSD-type stance of Russell and Cuban and the all-out optimism that computer and software vendors would like us to believe. To paraphrase Salomon

(2000), it is the educational rationale and not just the tools that count. Hence, computer usage in classrooms would lead to educational change and improvements in learning outcomes only if they are well-designed from a *pedagogical perspective to mediate specific learning objectives* (see Osborne & Hennessy, 2003; Soong, 2008).

1.4 Defining Pedagogy

There exists neither an exact nor universally agreed definition of the term *pedagogy* (Beetham & Sharpe, 2007). For example, the Cambridge Advanced Learners' Dictionary defines pedagogy as "the study of the methods and activities of teaching" while Lusted (1986) views pedagogy as a *process* that addresses the *reproduction* (i.e. construction by learners) of knowledge as well as its *production* (i.e. how one teaches in order to bring its *reproduction*). Hence, "through the prism of pedagogy, it [how one teaches] becomes inseparable from what is being taught and crucially, how one learns" (ibid, p.3). To Alexander (2008), "[p]edagogy is the act of teaching together with its attendant discourse of theories, values, evidence and justifications. It is what one needs to know, and the skills one needs to command, in order to make and justify the many different kinds of decision of which teaching is constituted" (p. 47) and is one of several interrelated aspects of the larger educational practice (Alexander, 1992), while Stierer and Antoniou (2004) define pedagogy as "the processes and relationships of learning and teaching" (p. 277).

In consideration of the definitions above, I define *pedagogy* in this dissertation as *the educational practices that teachers orchestrate in order to directly mediate learning*. Hence, while pedagogy is primarily a *teacher-initiated endeavour*, it is essentially a *student-centred activity*.

1.5 Overarching Research Intentions

Governments worldwide are putting unprecedented amounts of money and resources into promoting the use of ICT for learning, especially in schools (e.g. see Hennessy & Deaney, 2004; Amiel & Reeves, 2008). While changes in pedagogical approaches and classroom

practices (especially with the infusion of ICT into the classrooms) have the *potential* to change learning outcomes, this change *does not necessarily* occur. This finding has also been observed by Salomon (2000), who lamented that technology usage in education has been *domesticated* in the sense that technology is only allowed to do whatever the prevailing educational philosophy of learning allows it to do. Since traditional pedagogical approaches and classroom practices have always supported the view that knowledge can be abstractly transmitted from teacher to students, the role of technology has been domesticated to assist in this transmission process (usually in the form of learning *from* computers). Such findings have also been supported by Cuban (1993, 2001), who reported that school culture prevails over ICT usage and, hence, nothing in education has fundamentally changed as a result of ICT infusion.

Broadly, the research study described in this dissertation aims to assist in bridging the gap between ICT-infused physics learning environments and significant differences (improvements) in learning outcomes. I sought to contribute to the field by clarifying the design of an ICT-infused (computer-mediated synchronous communications) physics revision environment (collaborative problem-solving in a classroom-based setting) that would result in significant improvements in learning outcomes. Such a contribution would include the formulation of a framework/profile for the use of a discourse-centred computer-mediated collaborative problem-solving learning environment to fill a 'classroom niche' of in-school revision for physics, somewhat like how the University of Minnesota's *Cooperative Group Problem-Solving* approach is used by the Physics Department for teaching introductory physics (e.g. see Heller & Heller, 1999a), or how Harvard University Physics Professor Eric Mazur (e.g. Mazur, 1997; 2009) uses *Peer Instruction* for his large introductory physics lectures. The study will also contribute to the growing number of research studies on the potential of computer-mediated discourse for the purpose of understanding students' thought processes (e.g. Hung, 1996, 1998, 1999; Lund & Baker, 1999; de Vries et al., 2002) and to encourage more dialogic "science classroom talk" (Mortimer & Scott, 2003, p. 3) between teachers and students, and between students themselves.

In view of the preceding paragraphs, my research study focused on *designing, implementing, and evaluating* a computer-mediated learning environment for secondary school physics learning. Specifically, the overarching objective of my research study was to introduce a new *pedagogical practice* for physics revision in a *real-world classroom* so as to help students *revise better*. Working with the relevant stakeholders in school (i.e. Principal, Vice-Principal, teachers, students, computer laboratory technicians), I designed a learning intervention (introducing both new technology and pedagogy) targeted at a specific (but also typically mainstream) secondary school classroom in Singapore, and together, we changed the way physics revision was done in that classroom. The key terms of my research intentions are defined below:

Pedagogical practice – An approach involving teachers and students (and other stakeholders) working with various artefacts in order to mediate learning.

Real-world classroom – A classroom with no exceptional set-up or privilege, operating on the same resource and time constraints as other classrooms.

Revise – A revision of taught concepts, as opposed to the teaching of new content.

Better (when used in the term 'revise better') – An improvement in students' learning outcomes as measured quantitatively by test scores, and qualitatively by teachers' and students' perceptions, and students' work submissions.

Based on experience and initial discussions with the school's physics teachers, revision for physics (and also the other natural sciences) was typically done via the traditional methods of repetition-and-regurgitation and drill-and-practice. For the most part, revision lessons involved teachers providing students with questions posed in past examinations. Students, either individually or in small groups, worked on providing answers to these questions. The

teachers would then evaluate the students' submissions, and based on the correctness of the answers provided by the students, would decide whether further revision was necessary. It was possible for teachers to provide personalised attention and discuss various physics concepts for an individual or a small group of students. Based on the students' articulations during these personalised sessions, teachers could gain deep insights into the students' thought processes as they were solving a problem or 'thinking aloud' about a particular physics concept. However, it was difficult to provide such personalised instruction due to time constraints and as a result, the traditional mass approach to revision was still the norm.

A key weakness of the traditional revision method stems from the fact that teachers do not have access to students' thought processes *in situ*. This weakness is present because teachers are typically only able to peep into students' thought processes based on their explicit articulations (usually written or verbal). However, the traditional revision method – where students' articulations typically involve mainly providing teachers with the main steps (or worst still, only the final answer) of a proposed solution – does not provide teachers with deep enough insights into students' thought processes. Without deep insights into students' thought processes, teachers would be unable to identify specific students' cognitive gaps in the subject. This deficiency would result in revision lessons not providing the necessary scaffolding students need in order to overcome their misconceptions or misunderstandings.

Results of my earlier research (Soong & Chee, 2000; Soong, 2001) suggest that if student-pairs work collaboratively on solving physics questions via computer-mediated communications software technology, the protocol data (i.e. text-chat logs and computer white-board drawings) of their problem-solving and knowledge co-construction attempts could provide teachers with rich insights into the thought processes of students while they are solving the physics questions posed. Hence, instead of marking submitted answer scripts and attempting to infer where a particular students' knowledge gap might be, the protocol data (as captured by the computer) would provide teachers with microgenetic data that is articulated by the students themselves. Upon analysing this data, teachers can then deliberately and specifically address

individual students' cognitive gaps in the subject, based on their specific misconceptions or misunderstandings as manifested in the protocol data.

In view of my earlier research work, I propose that revisions based on using ICT as a means of allowing students to learn *through* computers could be used as a more effective means of physics revision for secondary science students, and my research study explored this claim further.

1.6 Epistemological Grounding and Theoretical Perspective

Because one's epistemological grounding and theoretical perspective serves as the lenses through which one views the world, I shall provide a discussion on my epistemological grounding and theoretical perspective upfront in the dissertation.

In reviewing the literature on conducting research studies, it is apparent that different authors propose different approaches to the research process (e.g. compare Creswell, 1994 with Crotty, 1998). As Crotty (ibid) acknowledged, "to add to the confusion, the terminology is far from consistent in research literature and social sciences texts. One frequently finds the same term used in a number of different, sometimes even contradictory ways" (p.1).

As a way out of this predicament, I will use Crotty's framework (p. 4) to provide an elaboration of my epistemological grounding and theoretical perspective. Crotty proposed that a good starting point when developing a research proposal is to answer two questions: "First, what methodologies and methods will we be employing in the research we propose to do? Second, how do we justify this choice and use of methodologies and methods?" (p.2) On answering the second question, Crotty explained that,

Justification of our choice and particular use of methodology and methods is something that reaches into the assumptions about reality that we bring to our work. To ask about these assumptions is to ask about our *theoretical perspective*.

It also reaches into the understanding you and I have of what human knowledge is, what it entails, and what status can be ascribed to it. What kind of knowledge do we believe will be attained by our research?...These are *epistemological* questions. (p.2; emphasis added)

My epistemological grounding and theoretical perspectives are as such: I believe that while objects may *exist* outside of the mind, *meaning* exist in objects due to our *interactions* with them. These interactions are *mediated* by psychological (e.g. language) or material (e.g. an unknotted handkerchief) artefacts, which we learn to use as a result of immersion in a particular community of practice (Lave & Wenger, 1991) or interaction within a particular culture. For example, before I bought my dog ('Zouki') from the kennel, both Zouki and I were already in independent existence. If something tragic had happened to Zouki *before* I had interacted with him, it would not have been a tragedy to me. However, upon buying him and interacting with him by teaching him to 'sit', 'shake hands', 'beg', 'turn around', 'play dead' and taking him for long walks in the park while playing with him 'fetch' with pieces of twigs picked up from the grass, even a slight cough would warrant my undivided attention. In the example above, it can be seen that my interaction with Zouki is mediated by language (e.g. "Zouki's a good boy!"; a psychological artefact) and the nondescript pieces of twigs (a material artefact) I picked from the ground to play 'fetch' with *my* dog. I had learnt that it is perfectly acceptable to teach Zouki all these 'tricks' (which are not what dogs in the wild would do) because others in my community have done the same. Said differently, our culture dictates the type of psychological and material artefacts we use for interacting with objects (living or otherwise), and it is our interaction with these objects that give them meaning. Consequently, we *act* towards an object in a specific way due to the *meaning* we ascribe to them as a result of our *interactions* with it. In other words, while *reality* may exist independently of one's mind (*realism* as an ontology), the *implication* of that reality is due to the *meaning* ascribed to it as a result of one's social, cultural, and historical *interaction* with it. Therefore, if we sufficiently *change* a person's sociocultural interaction with something, its *meaning* would change

correspondingly. Given a change in its *meaning* to us, there would be a subsequent change in how we *act* towards it.

In view of my emphasis on the sociocultural genesis of an individual's cognition and behaviour, and the prominence I place on psychological and material artefacts that mediate an individual's mind, it is evident that my epistemology is that of *social constructionism* (e.g. Crotty, 1998, p. 42-65) or *social constructivism* (e.g. Palinscar, 1998) and my theoretical perspective is that of *sociocultural theory* as espoused by Vygotsky (e.g. 1978, 1981). Briefly, to have a social constructionism/constructivism epistemology is to subscribe to the belief that all meaning is "being constructed in and out of interactions between human beings and their world, and developed and transmitted within an essentially social context" (Crotty, 1998, p. 42), and to have a sociocultural theoretical perspective on learning is to subscribe to the belief that,

...all learning originates in social situations, where ideas are rehearsed between people mainly through talk. As the talk proceeds, each participant is able to make sense of what is being communicated, and the words used in the social exchanges provide the very tools needed for individual thinking. (Mortimer & Scott, 2003, p. 3)

The importance of language and dialogue in Vygotsky's sociocultural theory is also highlighted by Mercer (2000), who emphasised, "Vygotsky proposed that there is a close relationship between the use of language as a cultural tool (in social interaction) and the use of language as a psychological tool (for organising our own, individual thoughts)" (p. 155). Additionally, Wertsch (1991) proposed that sociocultural theory (as espoused by Vygotsky) recognises (i) that individual meaning-making "appears twice: first, on the social level, and later, on the individual level; first between people (interpsychological), and then inside the child (intrapsychological)" (Vygotsky, 1978, p. 57), (ii) that human actions on both the social and individual planes are mediated by "language; various systems of counting; mnemonic techniques; algebra symbol systems; works of art; writing; schemes, diagrams, maps and

mechanical drawings; all sorts of conventional signs and so on” (Vygotsky, 1981, p. 137, as cited in Palinscar, 1998, p. 292), and (iii) that the best way to study meaning-making and human actions is via genetic or developmental analysis, since “the process of a given thing’s development in all its phases and changes – from birth to death – fundamentally means to discover its nature, its essence, for it is only in movement that a body shows what it is” (Vygotsky, 1978, p. 64-65).

Via these lenses, I do not view the research work described in this dissertation as uncovering universal rules or formulas (a focus that perhaps someone with an *objective* epistemology and a positivist/post-positivist theoretical perspective would have) that, if followed, would provide readers of my dissertation with specific instructions for revamping how science revisions should be done in their classrooms. In fact, I do not even seek to show direct causal relationships between specific 'dependent' (e.g. test scores) and 'independent' (e.g. number of hours spent studying) variables. Also, I do not see my work as being a personal narrative of my lived-in, at-that-point-in-time experience while operationalising the intervention in school (a focus that perhaps someone with a *subjective* epistemology and a post-modernist theoretical perspective would have). Rather, my research seeks to provide readers with an account of the learning environment my intervention provides, focussing on what I believe are the constructs that would provide for a change in sociocultural interactions between students and teachers and how they revise physics (an inter-personal, or sociocultural, dimension). In addition, I also provide a presentation and discussion of the theoretical basis for my intervention to bring about change on an intra-personal level (i.e. individual cognition such as knowledge and understanding, meta-cognition such as problem-solving strategies). In so doing, I aim to provide my readers with a better understanding of the context and unique situations surrounding my intervention, highlighting how my intervention may be seen as a means to change an existing, deep-rooted sociocultural classroom practice of physics revision, thereby helping readers to *reconstruct* their own learning interventions for their own purpose.

1.7 Overview of Dissertation

This dissertation is structured as such:

- Chapter One (this chapter) provides an introduction and background to my research study by explaining that the research work described herein follows the tradition of educational research that focuses on improving classroom practices. It explains the need to address secondary school physics education, and argues that computers may lead to improved learning outcomes if it has been well-designed from a pedagogical perspective to mediate specific learning objectives. I then state my overarching 'world view' by sharing my epistemological grounding and theoretical perspective.
- Chapter Two provides a discussion on my theoretical foundations that serve as the basis for the design of my physics revision intervention. I highlight the centrality of sociocultural practices on thought and behaviour, and show how sociocultural practices are significantly mediated by language and discourse. I also accentuate the differences between the two most common types of discourse and emphasise the unique affordances the written text offers over the spoken word. I then provide a discussion on science learning environments, and point out that of utmost importance in physics education is the explicit need to take into account students' prior knowledge.
- Chapter Three reviews key physics learning interventions. The review shows that the vast majority of physics interventions are based at a college/university level when targeting the primary or secondary level classes would probably yield higher benefits. The review also highlights the difficulty in implementing those key physics interventions in a Singapore secondary school settings – the middle/high school physics curriculum in the USA (where all the reviewed interventions originates) does not match the Singapore secondary physics curriculum, and although the college/university curriculum presents a closer match, the unique affordances available in a varsity setting makes it difficult to replicate in a Singapore secondary school setting. The review also shows that when computers were used in the interventions, their unique affordance of enabling a new communications genre were not exploited. Finally, the review shows that while students' consequences of using the intervention were similar (improved learning

outcomes), teachers' consequences of being involved in the intervention could differ as some interventions were very explicit about teachers' attempts at gaining insights into students' knowledge base and thought processes, while others were not.

- Chapter Four describes my physics revision intervention targeted at a typical, mainstream secondary school in Singapore. I explain how my physics revision intervention was designed based on the theoretical foundations expounded in Chapter Two, and describe the activities that go into each of the two unique processes that constitute the intervention. Thereafter, I provide a discussion on my research methodology and explain why design experiments (also termed design-based research) is an appropriate research methodology for this study, given my research questions, intentions, epistemological grounding, and theoretical perspectives.
- Chapter Five provides a discussion of the initial, small-scale pilot study that was conducted in order to gauge the overall effectiveness of the intervention from the perspective of students' learning outcomes. This pilot study was also conducted to ascertain whether the students would be agreeable to take part in the longitudinal main study, as well as whether the students' teacher perceived value in the intervention. The chapter also presents the results obtained in the pilot study, and provides a discussion of its findings.
- Chapter Six provides a discussion on the main research study, what was allowed to commence given the positive results of the pilot study. I also provide a discussion on the changes made to the intervention in order to conduct it during term time and within curriculum hours in school based on a whole class setting (as compared to the pilot study, which was conducted in school after standard curriculum hours). I describe the procedure and time-line for the main study, and provide a discussion on my data collection and analysis, elaborating how the research questions were answered in the study. The chapter also presents the results obtained in the main study, and provides a discussion of its findings.
- Chapter Seven concludes the dissertation by first mapping out my intervention to the C4 Intervention Evaluation model introduced in Chapter Three, highlighting the

similarities and differences between my intervention and the seven qualified interventions. It then provides a summary of the significant contributions this research study makes to educational research that aims specifically at improving classroom practices. A discussion on the implications of the findings of this research study (as well as future research work that may be conducted) on (i) the practice of physics revision in secondary schools, (ii) designing and implementing ICT-based interventions, and (iii) designing and implementing dialogic learning environments is also provided.

CHAPTER TWO

THEORETICAL FOUNDATIONS

In this chapter, I expound the theoretical foundations behind the design of my learning intervention. These foundations serve as the theoretical pillars of my intervention and provide the explanation to why certain aspects feature strongly in the design of my learning environment. I start the chapter by first highlighting the centrality of sociocultural practices on thought and behaviour; ultimately, how we think, act, and feel are a direct result of immersion in a particular community of practice or cultural setting. Next, I indicate how language and discourse facilitates the development of higher human mental functions. Thereafter, I illustrate that discourse may be spoken or written, and draw attention to the unique affordances the written text has over the spoken word. Finally, I provide a discussion on constructivist science learning environments, and highlight the importance students' prior knowledge plays in their learning of science concepts.

2.1 The Centrality of Sociocultural Practices on Thought and Behaviour

In his seminal ethnographic piece, anthropologist Clifford Geertz (1973; 2005) *thickly described* how established sociocultural practices dictated the behaviours of Balinese men to the extent that it governed how they gambled during cock-fights. He related that,

A man virtually never bets against a cock owned by a member of his own kingroup. Usually he will feel obliged to bet for it, the more so the closer the kin tie and the deeper the fight. If he is certain in his mind that it will not win, he may just not bet at all, particularly if it is only a second cousin's bird or if the fight is a shallow one. But *as a rule he will feel he must support it* and, in deep games, nearly always does. Thus the great majority of the people calling "five" [betting odds] or "speckled" [specific bird] so *demonstratively are expressing their allegiance to their kinsman, not their evaluation of his bird, their*

understanding of probability theory, or even their hopes of unearned income.

(2005, p. 74-75; emphasis added)

People's behaviours are dictated by established sociocultural practices; everything from how we greet to what we eat are shaped by immersion in a specific sociocultural setting (see also Bruner, 2008). In fact, sociocultural theory (as espoused by Vygotsky) is grounded on the tenet that human mental functioning evolves as a result of social and cultural interactions, and these interactions are mediated by language and/or other sign systems. In other words, how we think and subsequently act has a sociocultural genesis grounded in talk (Mercer, 2000), which Wells (2007) exemplified succinctly when he proclaimed, "Who we become depends on the company we keep and on what we do and say together" (p. 100).

Sociocultural theory has commonly been used to explore and explain how changes to an individual, group, or community occurs. For example, Arvind (2008) used sociocultural theory to explain how Goonga, a 'mute' boy in India, 'regained' his voice as a result of intervention at a community school:

To meaningfully integrate him into school processes, teachers encouraged him to actively participate in activities like morning assembly, sports, field trips, singing and book reading. A continuous engagement with the activities enabled Goonga to dislodge his previously held psychological structures that were barriers to literacy acquisition; and created possibilities to experience a new personal sense and meaning. Learning to read, write and spell emerged as the powerful ways to realize this goal-directed conscious behavior. Responding to an enabling school culture, the boy rapidly gained school competencies. The school teachers rechristened Goonga as Arun – the charioteer of the sun-god. As of now, Arun is shaping as a confident boy who loves to play, read and debate. He wants to become a teacher. The family is simply marveled at the transformatory potential of education. A field visit after a year affirmed the

stability of gains.

From the perspective of socio-cultural theorizing, [the] school's pedagogical practices provided a therapeutic context to Arun to reconstruct his identity by overcoming his disability in a naturalized fashion. The speech disorder was addressed by drawing out the child into other meaningful activities that not only compensated for the deficient articulation skills but also provided the platform to anchor literacy skills. The study established the importance of larger socio-cultural context at macro level in shaping psychological processes at micro level. (p. 385)

Since sociocultural theory "attempt[s] to theorise and provide methodological tools for investigating the processes by which social, cultural and historical factors shape human functioning" (Daniels, 2001, p. 1), it is generally true that sociocultural theory has been largely utilised for explanatory purposes (e.g. see Milne et al., 2006; Komura. 2008) while the pedagogic possibilities of sociocultural theory have remained under-theorised and under-researched (Daniels, 2001). However, increasingly, classroom practices are being looked at as sociocultural practices for the purpose of *introducing pedagogical change* (see also Palincsar & Brown, 1984; Brown & Palincsar, 1989). For example, Sato (2008) looked at Japanese language learning in a university foreign language setting as a sociocultural practice and from that perspective, "[i]nstead of viewing language learning as knowledge transmission...[now] learners must solve immediate problems together in communities of practice...[and] are not only consumers of linguistic and cultural knowledge but also producers" (p. 2). Sato highlighted the case of one non-Japanese student (Yan) who was made (it was the course requirement) to produce linguistic and cultural knowledge by way of creating and maintaining a web journal (blog). On his own accord, Yan engaged in a web-based community by discussing Japanese television dramas via his blog and soon found that, "Now I have been reborn as someone who likes writing" (ibid, p. 6). Sato then suggested that the introduction of blogging into language learning could change the sociocultural practice of language learning

such that “the teacher shifts out of the traditional role of transmitting knowledge to students... [into] one of facilitating activities and encouraging learners to communicate with people, express themselves, and participate in a community” (p. 8-9). In Sato's study, we see that the introduction of an artefact (blog) and pedagogy (engaging in web-based conversations with members of the web community) resulted in a new sociocultural practice, with corresponding behavioural and attitudinal changes.

In a similar fashion, we can view physics revision lessons in a specific classroom as a particular sociocultural practice. Students and teachers in that classroom think, act, and feel in a particular way predominately because of the way they *interact* with each other. Additionally, their *interaction patterns* are dictated by the prevailing sociocultural practice. Hence, if we want to change how students and teachers think and behave during physics revision, then we need to change the prevailing sociocultural practice. I propose that we can achieve this goal via two mutually reinforcing approaches that are informed by sociocultural theory and its “near relative 'activity theory'”. Both traditions are historically linked to the work of L.S. Vygotsky and both attempt to provide an account of learning and development as mediated processes” (Daniels, 2001, p. 1). Activity theory (e.g. Leont’ev, 1981; Engestrom, 1987; Kuutti, 1996) is a strand of sociocultural theorising “that seeks to analyze the development of consciousness within the practical social activity settings. By dialectically linking the person and the social structures, the objective is to gain a perspective on the local pattern of activity and the cultural specificities of thought and discourse” (Arvind, 2008, p. 379). As Daniels (2001) suggested, sociocultural and activity theory “are creating new and important possibilities for practices of teaching and learning in schools and beyond. They provide us with theoretical constructs, insights and understandings which we can use to develop our own thinking about the practices of education” (p. 2).

Activity theory is commonly used as a framework for analysing activity systems. For example, Barab et al. (2002) used “the central tenets of activity theory to analyze participation by

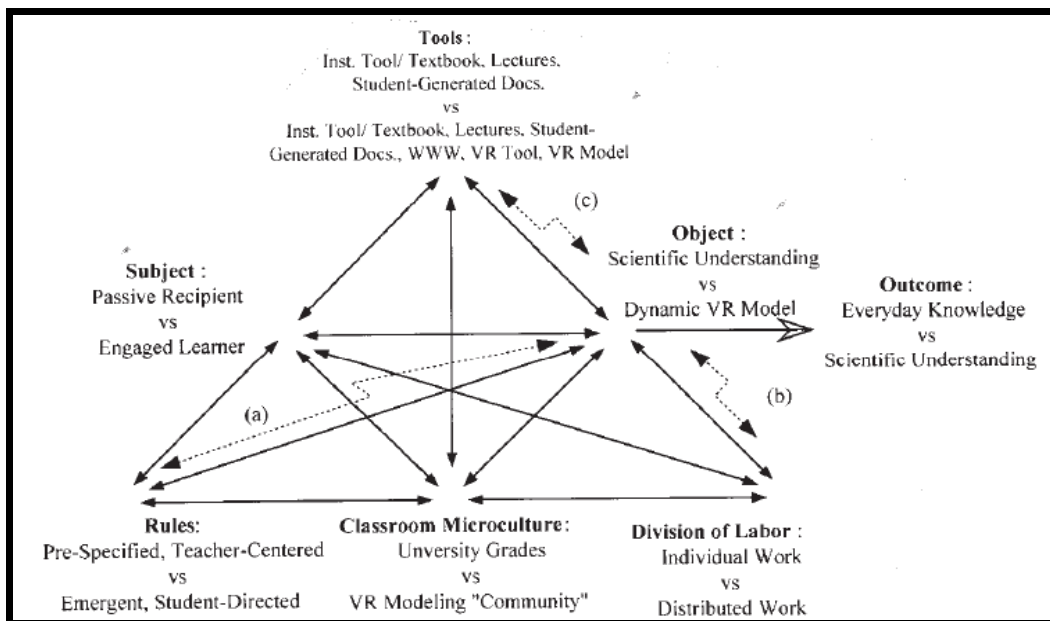


Figure 2.1: Barab et al's (2002) example of using Activity Theory as a framework to analyse an activity system (p. 103)

undergraduate students and instructors, illuminating the instances of activity that characterized course dynamics” (p. 76) and Figure 2.1 provides their depiction of the systemic tensions of a course activity of students via the activity theory framework. Similarly, Hardman (2008) analysed pedagogical practices in classrooms along activity theory dimensions and Figure 2.2 provides her depiction of a specific episode of a teacher's pedagogic practice.

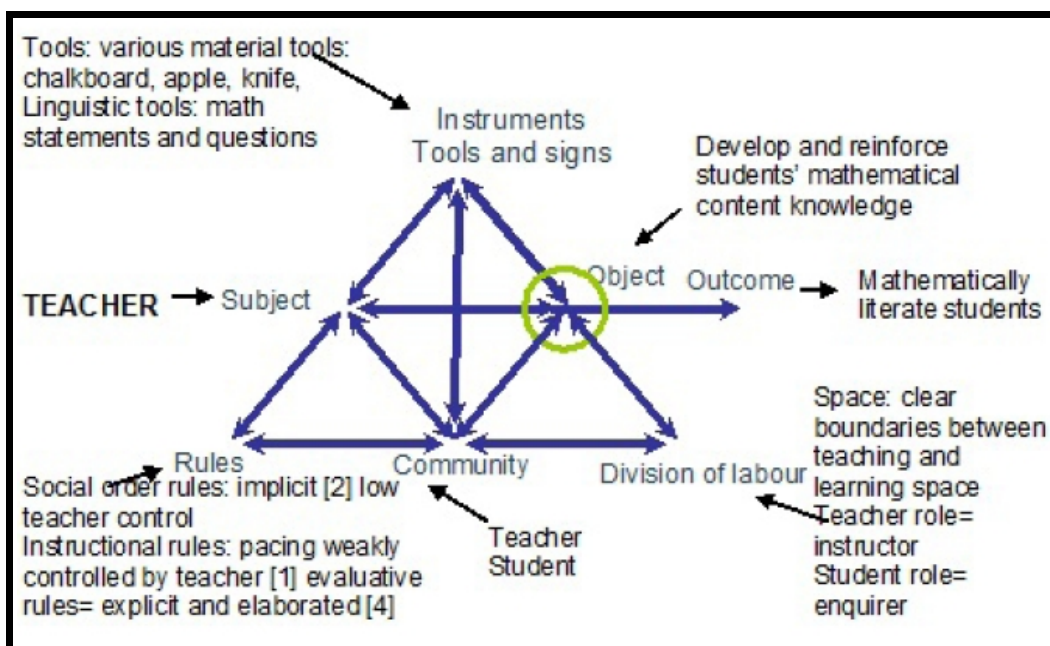


Figure 2.2: Hardman's (2008) example of using Activity Theory as a framework to analyse an activity systems (p. 89)

In my opinion, using activity theory as a framework for analysing activities may not yield a complete picture of a given activity as it is often difficult to specifically point towards one specific objective for, and outcome of, the object of an activity. In fact, an object at the core of a seemingly straight-forward activity may serve multiple objectives with multiple intended outcomes. For instance, recently I was comfortably seated by my desk working on my dissertation when I felt thirsty. Instead of asking my wife to get me a glass of water (as I usually do), I got up, walked to the kitchen, poured myself a glass of water and brought it back to my desk, where I quenched my thirst and then continued working. The objective of my activity appears straight forward – I wanted to quench my thirst and, hence, the described activity ensued. If I use activity theory to analyse the activity described above, the results may be summarised in Figure 2.3.

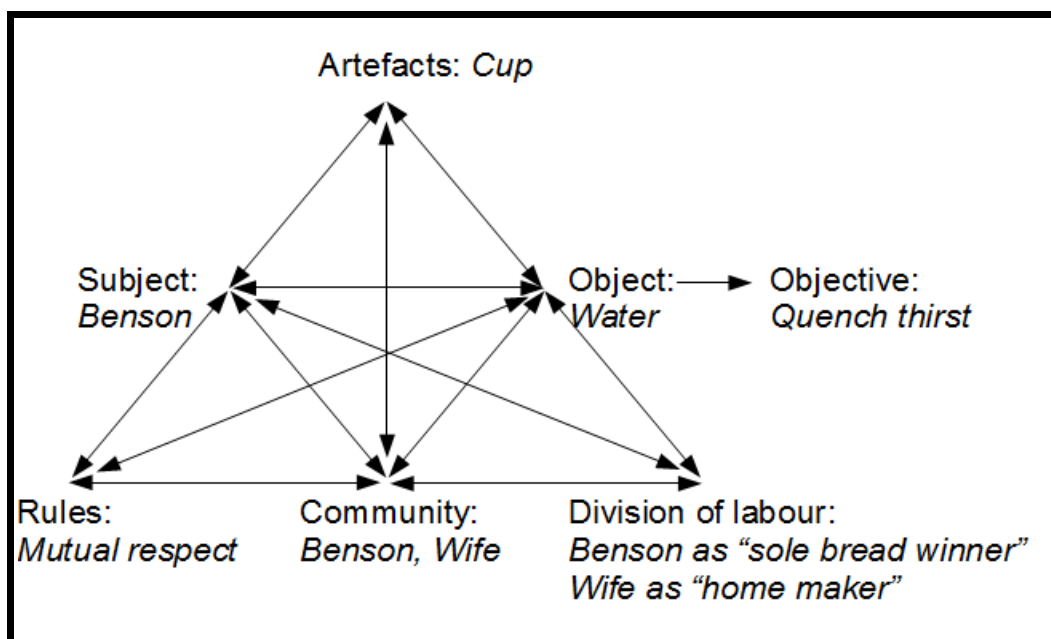


Figure 2.3: Using Activity Theory to analyse a 'simple' activity

As summarised in Figure 2.3, the *object* of the activity was water, and the *objective* of getting water was to quench my thirst. The *artefact* that mediated this activity was a cup, and the underlying contextual factors, such as the *rules* in the house, our household *community*, and our *division of labour* are provided in Figure 2.3. On one level, it could be argued that the

dimensions of activity theory provided a comprehensive framework for analysing the described activity. However, at a deeper level, this might not be so – while it might be the case where *an objective* of the activity was to quench my thirst, I got my own drink also because I wanted to stretch out a little. Additionally, I did not want my wife to nag at me for being lazy, and I also wanted her to know that I respected her time. Here, we see that a multitude of objectives (and intended outcomes) led to my apparently 'simple' activity, which cannot be succinctly analysed via an activity theory framework, since the relationship between the *object* of the activity (i.e. water) does not relate to one or more of the activity's intended outcomes (e.g. stretching out, preventing my wife from nagging at me). Nonetheless, what Figure 2.3 does is that it provides a reflection of a 'thirst quenching' activity and delineates the logical connectivity (e.g. me → cup → water → quench thirst) and relevant constructs (e.g. household context and setting) for how I had quenched my thirst. Said differently, activity theory works well in one direction, but less well in the other. As a *theoretical paradigm* (e.g. explanatory model), its *dimensions* provides the *logical connectivity* and *relevant constructs* for *artefact-mediated activities* (e.g. the activity was undertaken because I had wanted to quench my thirst, and I used a cup to mediate the activity). However, as a *theory to analyse activities*, its focus on *outcomes and objectives* that are *direct derivatives* of the *object* of the activity causes limitations (for another critique of activity theory, see Kozulin, 1998, p.24-31). Therefore, in this dissertation, I used activity theory as a theoretical paradigm and a basis for educational application, and not as a theory to analyse activities.

Firstly, using activity theory as an explanatory model, *changes to an activity's objective* necessitate a *change in the activity* itself, since every activity is essentially directed by a specific objective. With a change in activity, sociocultural practices change. Secondly, since *interactions are mediated by artefacts*, then the introduction of a *new and powerful artefact with a unique affordance* could well change how students and teachers interact with each other, thereby also *necessitating a change in sociocultural practices*. Therefore, any change programme that merely advocates changing *mindsets* (e.g. from a focus on teaching to a focus on learning) is likely to fail and similarly, and any change programme that replaces one tool

with an equivalent other (e.g. from paper-based textbooks to ebooks) is unlikely to bring about significant changes and improvements in practices, since neither the objective nor the artefact (from an *ideal*, as opposed to *material*, perspective) might have been meaningfully changed. In fact, from a sociocultural perspective, “mediating artifacts are fundamental constituents of culture and essential ingredients of all activity. They are features of the material world that have been and continue to be modified in their incorporation in goal directed human action... [and] must be seen not simply as facilitating or replacing mental processes, but as fundamentally shaping and transforming them” (Lecusay et al., 2008, p. 95). In other words, it is not “pedagogy *before* technology” as advocated by Watson (2001, p. 251; emphasis added) but rather, technology as both a *material artefact* with *unique affordances* as well as *ideal* aspects embodied in them which allow for a *change in pedagogy* that would lead to changes and improvements in classrooms.

An implementation of both approaches (changing of an activity's objective as well as introducing a new mediating artefact) were utilised in the design of my intervention, and in Chapter Four, I provide details and illustrations on how this perspective shaped the design of my learning intervention.

2.2 Talk and Development

In line with my sociocultural theoretical perspective, language and social interactions form the genesis of human development and learning, where “[l]anguage acquisition and use are seen as having a profound effect on the development of thinking” (Rojas-Drummond & Mercer, 2003, p. 100). From a Vygotskian perspective, *language* is a particularly powerful artefact because it shapes human mental development via three interrelated ways. Firstly, it serves as a *cultural tool* that facilitates the sharing and development of meaning amongst members of a community (I shall call this tenet one, or T1 for short). Secondly, it serves as a *psychological tool* through which individuals structure their own thought processes (T2). Thirdly, it serves as the *conduit* through which social practices and meaning are effectively intermeshed with individual thoughts and in so doing, transform them (T3).

Perhaps a contemporary and illustrative example would be useful to expound the three tenets of language and its developmental powers. In the recent 2009 Miss Singapore-World pageant, winner Ris Low gave a public interview that generated much controversy among the Singaporean community. The source of controversy started out as criticisms against her poor diction (e.g. pronouncing 'bikini' as 'bigini') and usage of various (supposedly) English words (see RazorTV, 2009a, for the interview that sparked the controversy). One word, in particular, turned viral among the Singaporean community and started appearing on prime-time television (e.g. see YouTube, 2009a) and all over the internet and other mass-media. A few music videos were even especially made (e.g. YouTube, 2009b/c). This was how it all started: During an interview as a contestant, Ris Low was asked what she would wear if she is feeling "naughty". Her response was, "Something red and loud, something, you know, boomz". As Straits Times reporter, Nicholas Yong (2009a) blogged,

I don't know about you, but I've been hearing the word 'boomz' a lot lately. Whether among friends or strangers, on the MRT [train] or the bus, on Facebook or YouTube, it's been resounding everywhere....It's become apparent to me that Ris Low, the unwitting pop culture phenomenon of 2009, has created a word that will surely become a permanent part of our cultural lexicon....And yet, no one quite knows what it means.

So, we see that language has served as the cultural tool that facilitates the sharing and development of the meaning of the word 'boomz' amongst members of the Singaporean community (T1). Also, imbued in Yong's writing is evidence that language served him as a psychological tool through which he structured his sentences as he penned (or typed out) his article (T2). However, contrary to Yong's (ibid.) thoughts, Ris Low did not independently create the word, 'boomz'. She revealed in an interview held after the Miss Singapore-World fiasco (she gave up her crown) that "'boomz' is actually a word meant to be something that is loud, something that is strong, something that has an effect on people...the comics whereby

the car crash into it and then it goes 'boomz'...explosion" (RazorTV, 2009b). Her utterance provides us with an insight into the incipience of the word 'boomz' in Ris Low's mind – it already existed in the world of comic strips and car crashes! What Ris Low had done was to internalise this word and made it her own (T3). Now that she has shared her meaning of that word (through dialogue, I should add), we are able to internalise it and, as Yong (2009b) cheekily muses, "Personally, I can't wait to see how the use of the word evolves. In fact, I'm feeling pretty boomz about it."

Given the profound effect and influence *language* (or *speech*, see Wertsch, 1979; or *talk*, see Mercer, 2008) has on the development of one's thinking, "many researchers have put forward persuasive and influential arguments for the importance of the quality of teacher-student dialogue on the development of children's understanding of science and other curriculum subjects" (Mercer, *ibid*, p. 92). Examples include the research work of Lemke (1990), Wells (1999), as well as Mortimer and Scott (2003). Lemke's (1990) *social semiotic* approach draws attention to his thesis that learning science "means learning to communicate in the language of science and act as a member of the community of people who do so" (p. 1). To Lemke, scientific reasoning is learning "by talking to other members of our community, we practice it by talking to others, and we use it in talking to them, in talking to ourselves, and in writing and other forms of more complex activity (e.g., problem-solving, experimenting)" (p. 122). As for Wells (1999), his *semiotic apprenticeship* approach "accord[s] a special place to language, seeing in the various genres of spoken and written discourse a kit of tools that performs a dual function, both mediating participation in activity and simultaneously providing a medium in which activity is represented and thus made available to be reflected upon" (p. 164). For Mortimer and Scott (2003), their research work has showed them that "[i]t is through talk that the scientific view is introduced to the classroom. Talk enables the teacher to support students in making sense of that view. Talk enables the students to engage consciously in the dialogic process of meaning making, providing the tools for them to talk through the scientific view for themselves" (p. 3). These researchers, who also have a sociocultural theoretical perspective, highlight the importance of talk (or discourse) because "[t]he most fundamental concept of

sociocultural theory is that the human mind is *mediated* (Lantolf, 2000, p.1; emphasis in original) predominately by a process Mercer (1995) described as “the guided construction of knowledge”, which is “a communication process...in which one person helps another to develop their knowledge and understanding” (p. 1).

Looking at talk from a classroom perspective, there are two broad levels of potential benefits which discourse in class could bring to the students, namely individual-level benefits (intra-personal benefits) and social-level benefits (inter-personal benefits). At the individual level, meaningful discussions in classrooms can lead to deep learning as it facilitates the generation of contextual knowledge and scientific conceptual understanding (e.g. see Hsi, 1997) and promotes reasoning in students (e.g. see Piaget, 1972). By providing an opportunity for students to be exposed to the views and beliefs of others, it may motivate the revision of ideas and misconceptions (Strike & Posner, 1985). In addition, “[d]ialogue and discourse encourages the higher order thinking skills of cognitive conflict and resolution in providing context and a mechanism for explanation, justification and reason” (Lockyer et al., 1999, p.56).

At a wider, social level,

The social environment...is truly educative in its effects in the degree in which an individual shares or participates in some conjoint activity. By doing his share in the associated activity, the individual appropriates the purpose which actuates it, becomes familiar with its methods and subject matters, acquires needed skill, and is saturated with its emotional spirit. (Dewey, 1916, p. 26)

In the quote above, Dewey highlighted the participatory and interactive role learners play in their education. It is the learners’ interactions with instructors and other learners that “give them perspective, place them within a community of learning, and contribute to their mastery of concepts and skills” (Price & Petre, 1997, p. 1041). I view such social interactions (and the

discourse which comes along with them) as vital in nurturing this spirit of learning that Dewey feels so passionate about.

Given the fundamental relationship meaningful talk has with mental development, my intervention encourages meaningful classroom discourse, and in Chapter Four, I provide further implementation details of how this was done.

2.3 The Written Text and the Spoken Word

Discourse may take many forms and occur in different ways, but the two most common ways are by talking or by writing. As Wells (1999) observed, in addition to language used during speech (or talk), Vygotsky also "had a keen interest in the development of writing...[and] saw mastering written language as playing a critical role in the development of 'the higher psychological functions'" (p. 267). In broad terms, Olson (2006) highlighted that,

The general reasons people turn to writing are well known; writing preserves language across space and through time. Indeed, these two facts account for the two basic uses of writing that have been found historically and continue to dominate contemporary societies, namely, the use of writing for record keeping (through time) and for writing letters (across space). (p. 137)

While Nystrand (2006) disagreed with Olson's view on the historical purpose of writing and offered an alternate perspective, stating that writing started "as an alternative system of communication...[which] offered features and resources unavailable to speakers yet meaningful to international traders who had no need even to speak the same language" (p. 161), embedded in his statement is his implicate agreement that what is written (or recorded) is transportable through time and across space.

Indeed, from the perspective of human mental development, the written text offers unique affordances which the spoken word does not (and vice versa). These unique affordances may

be looked at from the view of the recipient and the originator. Firstly, because written text is transportable through time and across space, the recipient is in practical control of this physical artefact (the written text) and may therefore deal with the artefact in a way s/he deems fit (e.g. following a recipe for cooking Chicken Maryland, or collating recipes together for further dissemination and/or future consultation purposes). Of particular interest to educational researchers is the *reflective endeavour* a recipient must put into making sense of the written text (Wells, 1999). Such an endeavour exists because while writing is an effective way of representing *what* people say, "it is hard to capture in writing *how* people say things" (Hannon, 2000, p. 17; emphasis in original) and as a result, more effort needs to be expended in order to derive at the originator's intended meaning, when compared to speech (see Olson, 1994 and/or Gee, 2006 for examples of how seemingly simple printed sentences may have vastly different interpretations depending on how they are said).

Secondly, from the originator's perspective, the making of the written text involves "much greater engagement and commitment...because a new and independent material and semiotic artifact is created as the outcome of writing, but not in the case of reading" (Wells, 1999, p. 287).

Because of the effort, engagement and commitment that has been put into its making,

...it is in writing rather than in reading that the power of written language to create new meaning is most fully exploited....For it is in solving the problems of meaning making that occur in creating a written text for others that writers of all ages and stages of development both develop their mastery of the craft and extend and deepen their individual understanding. In Vygotsky's words, "The individual develops into what he/she is through what he/she produces for others" (1981, p. 162). (Ibid.)

However, Gee (2006) provided a caveat by stating that the benefits of writing are not definite. He cautioned that, "Writing, like other technologies (e.g., television, computers, video games), does not have necessary effects, but it does have affordances that lead it relatively predictably to have certain sorts of effects in certain sorts of contexts" (p. 153).

From a classroom perspective, the act of purposeful writing engages students more fully, and because students' written work is transportable across space and through time, it allows for teachers (and the students themselves) to review and reflect on what the students had written. Hence, if students' discourse may be naturally operationalised in a 'written' format which is suitable for review and critique, then such an approach would greatly aid in the development of higher mental functioning in the learner. In Chapter Four, I provide further details on how this was achieved in my intervention.

2.4 Constructivist Science Learning Environments and the Importance of Students' Prior Knowledge

Increasingly, science education is being "largely shaped by the philosophy of constructivism" (Abdullah, 2009, p. 3). A key tenet of constructivism is the belief that "*meaningful* learning can take place only when the learner is able to relate the information provided by a teacher to their existing knowledge" (Taber, 2003, p. 732; emphasis in original; the other tenet is the active participation of learners; see also Mortimer & Scott, 2003). In other words, constructivist learning theory recognises that a student's mind is not a *tabula rasa*; students come to classrooms with prior knowledge and preconceptions, and they interpret what their teachers are saying based on these preconceptions. As Ogborn (2004) explained in his review of physics education,

Perhaps the strongest result to emerge from this research [in physics education] has been the fundamental importance of the ideas students hold about the physical world, in deciding how they understand what they are taught. The point is ultimately simple and obvious: everybody understands

what they are told as a kind of 'best fit' to what they already know. (p.85)

Against such a backdrop, it has been recognised that students' preconceptions (or misconceptions or prior learning) can often impede their learning and understanding of normative science concepts (for e.g. see McDermott et al., 1987; Goldberg & Anderson, 1989; Trowbridge & McDermott, 1980; Trowbridge & McDermott, 1981; Aguirre, 1988; Bowden et al., 1992; Voska & Heikkinen, 2000; Taber, 2003; Adbo & Taber, 2009). Indeed, Kang et al. (2005) noted that "many science educators...have an interest in students' pre-instructional or alternative conceptions because knowing them is an essential starting point to develop strategies and/or processes for introducing new scientific concepts," adding that, "[t]he research on students' alternative conceptions in various content domains rapidly expanded during the 1980s...and remains an important agenda to be investigated" (p.1038). An instance of how students' preconceptions impede their learning is provided by Ogborn (2004), who suggested that perhaps due to students' intuitive understanding and experience with moving and non-moving objects, they "regularly refuse to believe the First Law [of Motion], and import into mechanics ideas of their own about a 'force' needed to keep objects in motion" (p.85). Unlike domains such as Civics or Moral education where the issues involved may be based largely on societal opinions which may vary from country to country or community to community, physics concepts and principles are conceptually clear, with universally accepted and established normative views on the phenomena addressed by physics (e.g. Newton's Laws of Motion), which students are required to learn. The recognition of students' preconceptions vis-à-vis normative scientific views has led to an increased focus on uncovering, understanding, and dealing with students' preconceptions and misconceptions. For example, the Department of Physics at Montana State University (Montana, 2009) maintains a website of common students' physics misconceptions, while the *Comprehensive Conceptual Curriculum for Physics* (C3P) project at the University of Dallas (Dallas, 2009) provides training workshops for teachers, which covers common preconceptions and misconceptions that many American high school physics teachers and college professors have recognized in their students. This focus and importance of addressing students' preconceptions/misconceptions in science

learning environments is epitomised by Olenick (2005), who remarked that,

Our goal is for students' preconceptions to be lost in time and our stakes are high. Without the next generation of scientists and a citizenry that can make intelligent and informed decisions about science, our future will be lost. (p. 16; emphasis added)

Hence, from a physics learning environment perspective, there is a need to explicitly take into account students' prior knowledge and in Chapter Four, I provide further details on how this was achieved in my intervention.

2.5 Chapter Summary

In this chapter, I highlighted the centrality of sociocultural practices on human thought and behaviour, which are succinctly expressed by Wells' proclamation that "who we become depends on the company we keep and on what we do and say together". I showed how sociocultural practices are significantly mediated by "talk" and identified that language and discourse serves as (i) a *cultural tool* that facilitates the sharing and development of meaning amongst members of a community, (ii) a *psychological tool* through which individuals structure their own thought processes, and (iii) the *conduit* through which social practices and meaning are effectively intermeshed with individual thoughts and in so doing, transform them. I then indicated that from a classroom perspective, engaging students in discourse includes individual-level benefits (i.e. intra-personal benefits such as knowledge gains) and social-level benefits (ie. inter-personal benefits such as the appreciation of the subject and the community). Thereafter, I accentuated the differences between the two most common types of discourse – the written text and the spoken word, and from a classroom perspective, emphasised the unique affordances the written text offers. Finally, I concluded with a discussion on science learning environments, and pointed out that of utmost importance in physics education is the explicit need to take into account students' prior knowledge, since students interpret what a teacher says according to what they already know. Ultimately, the

theoretical foundations expounded in this chapter serve as the pillars of my intervention, which is described in detail in Chapter Four.

CHAPTER THREE

REVIEW OF KEY PHYSICS LEARNING INTERVENTIONS

In this chapter, I review physics learning interventions that fulfil a specific criteria. These criteria, which are elaborated in section 3.1, help me ensure that relevant physics learning interventions are identified and reviewed. On the whole, this review serves the primary purpose of synthesising the field and indicating what has been previously accomplished, and what has not.

3.1 Coverage Strategy and Inclusion Criteria

Given that a key interest in educational research is to understand how students learn, and how we can assist them to learn better (see section 1.1), physics education research has been interested in helping students learn better since at least the 1970s. During the 1970s and 1980s, there were considerable research interests in examining the differences between experts and novices in an attempt to help physics students perform at an 'expert' level (e.g. see Simon & Simon, 1978; Larkin, 1981). From the 1980s to 1990s, significant research efforts went into uncovering students' preconceptions pertaining to a variety of physics concepts (starting with Newtonian mechanics; e.g. Trowbridge & McDermott, 1981; Bowden et al., 1992) in order to facilitate conceptual change (Strike & Posner, 1985; Nersessian, 1998) in students. From the late 1990s onwards, considerable research efforts have been made towards improving teaching and learning practices (i.e. interventions) in science classrooms. Given the myriad of published learning interventions for science education, which vary in both scale and scope, it is not plausible to review all such learning interventions. Hence, included in this chapter are physics learning interventions that fulfil the following criteria: (i) they have been implemented in a whole-class setting for at least an entire academic term, (ii) they cover a range of introductory physics topics (i.e. does not focus on only a particular physics topic/concept, such as only electric circuits or Newtonian mechanics), (iii) the intervention is not predominately laboratory-based (i.e. it focuses mainly on the classroom aspects of physics

lessons, not the practical/laboratory aspects), (iv) they have empirical evidence to support their claim of improved learning outcomes for students, (v) they provide clear guidelines for what teachers and students are to do (i.e. they are not generic approaches such as 'discovery learning', 'context-based instruction/assessment', etc.), and given that physics curriculum and classroom technology has changed significantly in the past decades, (vi) they are no older than two decades. These criteria have been selected so as to be in line with my research intentions of designing, implementing, and evaluating an ICT-based physics revision intervention for a secondary school in Singapore.

To locate relevant studies, I searched ERIC, ISI Web of Knowledge (WoK), APA PsycINFO, and Google Scholar (GS) for the terms (i) “*physics*” and “*learning intervention*”, (ii) “*physics*” and “*teaching intervention*”, as well as, (iii) “*teaching introductory physics*”. Prior to my searches, I spoke to close associates who are teachers and lecturers involved in physics education so as to obtain their insights on physics learning interventions that might meet my criteria. Tables 3.1, 3.2 and 3.3 provide a summary of my findings from my search efforts:

Table 3.1: Summary of search results for “*physics*” and “*learning intervention*”

Search terms: “ <i>physics</i> ” and “ <i>learning intervention</i> ”	ERIC	WoK	PsycINFO	GS
Number of hits	0	0	0	136

Table 3.2: Summary of search results for “*physics*” and “*teaching intervention*”

Search terms: “ <i>physics</i> ” and “ <i>teaching intervention</i> ”	ERIC	WoK	PsycINFO	GS
Number of hits	4	5	0	244

Table 3.3: Summary of search results for “*teaching introductory physics*”

Search terms: “ <i>teaching introductory physics</i> ”	ERIC	WoK	PsycINFO	GS
Number of hits	14	15	0	540

I went through each of the studies (i.e. first only looking at the abstracts and then, if necessary, the entire document and where appropriate, the references therein), selecting those that were relevant to my review based on the criteria justified earlier. This activity was a

time-consuming process that was at times frustrating since, by and large, the vast majority of 'hits' did not pertain directly to physics learning interventions. In addition, the vast majority of 'hits' that did deal with physics learning interventions were mainly small-scale studies that did not fulfil the criteria set (most were focused on specific physics concepts and/or were implemented and evaluated in less than one academic term). However, given the hundreds of references to follow in GS, it could be inevitable that I might have missed out on a few relevant physics teaching methods. Nonetheless, I found all the research studies which I had already known about, as well as those that were pointed out earlier by my associates in the physics education field. In total, my search revealed a total of seven physics learning interventions that fulfilled the criteria set, and they are:

- Mazur's *Peer Instruction* (PI; e.g. Mazur, 1997, 2009)
- Heller and Heller's *Cooperative Group Problem Solving* (CGPS; e.g. Heller & Heller, 1999a; 1999b)
- McDermott and colleagues' *Tutorials in Introductory Physics* (TIIP; e.g. McDermott et al., 2002)
- Redish and colleagues at the Activity-based Physics Group's *Activity-based Physics Suite* (ABPS; e.g. Redish, 2003)
- VanLehn and colleagues' *Andes Physics Tutoring System* (Andes; e.g. VanLehn et al., 2005)
- Minstrell and colleagues' *Diagnoser Project* (Diagnoser; e.g. Thissen-Roe, Hunt & Minstrell, 2004)
- Etkina and colleagues' *Extended Physics Program* (EPP; e.g. Etkina et al., 1999)

It is worth pointing out that ABPS has elements of TIIP, CGPS, and PI, and EPP has an element of CGPS.

3.2 The C4 Intervention Evaluation Model

In order to synthesise and review the qualified physics learning interventions, I analysed them based on my adaptation of the *design brief* guidelines developed by Ametller et al. (2007) and elaborated in Leach et al. (2009). An adaptation was required as the interventions analysed were described in *large grain size* (Leach & Scott, 2008) terms, whereas the prescribed *design briefs* are meant to provide for finer grain-size descriptions. I have termed my adaptation of the design brief guidelines the *C4 Intervention Review Model*, which is depicted in Figure 3.1.

Intervention Context					
Curriculum	Students	Teachers	Institutional Affordances and Constraints	Intervention Type	Other Stakeholders
Intervention Content					
Topics and Concepts			Assessment		
Intervention Concept					
Theoretical Underpinnings	Activities Outside of Classroom	Activities Inside of Classroom	Critical Pedagogical Concept		
Intervention Consequence					
Students	Teachers		Other expected consequences		

Figure 3.1: C4 Intervention Review Model (adaptation of Leach et al.'s (2009) *Design Brief*)

Intervention context provides a description of the context for the intervention:

- *Curriculum*: The physics curriculum/level addressed by the intervention
- *Students*: The academic level of the students, along with any specific characteristics that could influence the students' ability to learn physics
- *Teachers*: The experience of the teachers, along with any specific characteristics that could influence the teachers' ability to teach physics
- *Institutional affordances and constraints*: Class sizes and facilities, along with other infrastructural and/or policy constraints

- *Intervention-type*: What the intervention focuses on (e.g. all aspects of physics teaching, or assessment, or revision aspects)
- *Other stakeholders*: Other stakeholders who are directly involved in the intervention (e.g. teaching assistants)

Intervention content provides a description of the content coverage of the intervention:

- *Key topics and concepts* : The main topics and concepts addressable by the intervention
- *Assessment*: How the students are assessed in order to gauge the intervention's effectiveness

Intervention concept provides a description of the intervention's pedagogical strategies and instructional sequences:

- *Theoretical underpinnings*: The theoretical underpinnings that the intervention are based on (e.g. constructivism, cognitive apprenticeship)
- *Activities outside of classroom instruction*: The activities that occur outside of classroom instruction that are critical for the intervention to work
- *Activities during classroom instruction*: The activities that must be done during classroom instruction that are critical for the intervention to work
- *Critical pedagogical concept*: The chief pedagogical consideration that is considered as the heart of the intervention

Intervention consequence provides a description of the consequences resulting from the successful implementation of the intervention:

- *Students*: The outcome of the students as a result of the intervention
- *Teachers*: The outcome of the teachers as a result of the intervention
- *Other expected consequences*: Any other expected consequences as a result of the intervention

Based on this model, the proceeding sections will discuss each one of the four 'C's in turn.

3.3 Reviewing Interventions' "Context"

Based on the information summarised in Table 3.4, the review indicates that from a context perspective, the vast majority of physics interventions occur only at a college/university level. I believe that this is due to a 'convenience' factor; certainly no teacher/instructor or researcher would claim that interventions in primary, secondary or pre-university settings are less important. In fact, Lui (as cited in Gunasingham, 2009) believes that it is more important to improve science teaching practices when students are in primary and secondary schools. It is therefore unfortunate that out of a total of seven, six of the qualified interventions are conducted so late into students' academic journey, since more students would have been interested to read physics at an undergraduate/postgraduate level if those interventions were introduced much earlier. Also, it is likely that these six interventions are not readily implementable in secondary schools due to the unique affordances available within a college/university institution. For example, in a varsity setting, there are teaching assistants who share the teaching workload with lecturers, and lecturers have the ability/flexibility to change assessment items. Such affordances are not available in a typical secondary school, whereby the constraints are such that a teacher is solely responsible for teaching a specific subject to a specific class. Additionally, secondary schools take standardised examinations and hence, lack the ability to customise their assessment methods. Perhaps it was for this reason that only 5% of all PI practitioners surveyed (see Fagen et al., 2002) reported that they were from high schools, with no one reporting that they were from a middle school. In fact, some of the reported challenges to implementing PI (see Fagen et al., *ibid*) as reported by PI practitioners themselves seem particularly relevant to secondary school teachers:

- the time and energy required to develop ConcepTests – since most of the pre-written ConcepTests addresses the college/university curriculum

Table 3.4: Cross-intervention comparison of Intervention "Context"

Intervention Name	Intervention Context					
	Curriculum	Students	Teachers	Institutional Affordances and Constraints	Intervention Type	Other Stakeholders
<i>Peer Instruction (PI)</i>	Introductory physics typically at university/college level	Typically (very high-achieving) undergraduates	Typically lecturers	Large hall aided by ICT such as "clickers". Ability to change curriculum and assessment items	In-class large-scale lectures	None specified
<i>Cooperative Group Problem Solving (CGPS)</i>	Introductory physics typically at university/college level	Typically (high-achieving) undergraduates	Typically lecturers and teaching assistants	Large halls for lectures and small rooms/labs for recitation and laboratory sessions Ability to change curriculum and assessment items, as well as change classroom set-up	In-class large-scale lectures with small-scale laboratory and recitation sessions	Teaching Assistants
<i>Tutorials in Introductory Physics (TIIP)</i>	Introductory physics typically at university/college level	Typically (high-achieving) undergraduates	Typically lecturers and teaching assistants	Small rooms for recitation sessions Ability to change curriculum and assessment items, as well as change classroom set-up	Small-scale recitation sessions to supplement large-scale lectures	Teaching Assistants
<i>Activity-based Physics Suite (ABPS)</i>	Introductory physics typically at university/college level	Typically (high-achieving) undergraduates	Typically lecturers and teaching assistants	Large hall for lectures aided by ICT such as data-loggers. Small rooms for recitation sessions, and small laboratory rooms aided by ICT such as data loggers and visualisers. Ability to change curriculum and assessment items, as well as change classroom set-up	In-class large-scale lectures with small-scale laboratory and recitation sessions, but customisable according to needs	Teaching Assistants
<i>Andes Physics</i>	Introductory physics typically	Typically undergraduates	Computer (AI)	Ability to change curriculum	Individual Problem-Solving	None specified

<i>Tutoring System (Andes)</i>	at university/college level	(Naval Academy Cadets)		and assessment items		
<i>Diagnoser Project (Diagnoser)</i>	Physics typically at middle/high school level (State of Washington standards for education)	Typically Middle/High School Students	Computer (AI)	Need to take standardised examinations	Individual Formative Assessment and Feedback	Administrators and teachers in school
<i>Extended Physics Program (EPP)</i>	Introductory physics typically at university/college level	At-risk (of failing physics) undergraduates who are specially selected to take the course	Typically lecturers and teaching assistants	Ability to change curriculum and assessment items, as well as change classroom set-up.	In-class large-scale lectures with small-scale laboratory and recitation sessions	Teaching Assistants and Course Coordinator/Administrator

- the quantity of material to cover in a semester often makes it difficult to devote class time to ConcepTests – since teachers in secondary schools are expected to directly teach physics concepts during class time, rather than in Mazur's case (e.g. see Mazur, 2009) when students read and review textbook materials before coming to class (see section 3.5)
- teachers' scepticism of the benefit of students' discussions over lecture time – since discussions are only fruitful if students already have basic knowledge about the concepts being discussed
- students' resistance to the method – since students in secondary schools prefer to be taught in class, rather than learning by themselves at home
- difficulty in engaging students in class discussions – since many secondary school students lack the skills needed for fruitful peer discussions

There are two ICT-centred and five non-ICT centred interventions. Interestingly, both the ICT-centred interventions use some form of 'artificial intelligence' to address the revision aspects of physics education, while the five non-ICT centred interventions address the teaching aspects of physics education. When the non-ICT centred interventions use ICT, the ICT used does not contain 'artificial intelligence' and merely performs collating and visualising tasks. Broadly, when ICT is used in these seven interventions (i.e. Andes, Diagnoser, ABPS, PI), the main affordances exploited are (i) the speed at which it can processes information, as in the case of PI, ABPS, and Diagnoser and (ii) its ability to replicate and have each replicate follow the exact same instructional sequence, as in the case of Andes. It is interesting that other (more social) affordances of ICT, such as its ability to facilitate a new genre of communications (Stahl, in prep) are not exploited in these interventions, although they have been used in other educational settings (e.g. Hung, 1996; de Vries et al., 2002; Stahl, 2009).

The qualified physics interventions range from transforming lecture practices (e.g. PI), recitation practices (e.g. CGPS, TIIP), laboratory practices (e.g. ABPS), problem-solving

practices (e.g. Andes), assessment practices (e.g. Diagnoser), and even administrative practices (e.g. EPP) and hence can offer reference models for virtually all aspects of physics education.

3.4 Reviewing Interventions' "Content"

As summarised in Table 3.5, some interventions are topic and concept agnostic whereas others are based on misconception research and, hence, addresses specific topics and concepts. For interventions that are topic and concept agnostic, the focus is on pedagogical approaches that help students learn better. For example, Smith et al. (2009) showed that it is the pedagogy of having *peer discussions* centred on a particular physics concept that leads to improved students' performance, whereas for CGPS, Heller and Heller (1999b) argued that it is students' immersion in their "culture of expert practice" (p. 5) which "bring these [internal thinking] tacit and hidden processes in the open, where students can observe, enact, and practice them with the help of the teacher and other students" (p. 6) that transforms students from novices into experts. For EPP, it is the explicit and comprehensive support for 'at-risk' students that helps students to improve. Further discussions on pedagogical approaches are provided in section 3.5.

For interventions based on specific topics and concepts, all these interventions are based on misconception research (whether driven by stable cognitive structures or activation of inappropriate concepts; see Hammer, 1996). Given that the popularisation of misconception research started with Newtonian mechanics (e.g. Trowbridge & McDermott, 1980; 1981), all non-topic/concept agnostic interventions address force and motion. Also, the topics that the college/university interventions address are similar (e.g. electricity, magnetism, waves, optics) presumably due to an informally agreed upon curriculum, whereas the middle/high school intervention excluded certain topics (e.g. optics, electricity and magnetism) while including other topics (e.g. properties of matter), presumably due to differences between the university and pre-university physics curriculum. It should be noted that the secondary school physics curriculum in Singapore includes optics, electricity, magnetism, as well as properties of matter.

Hence, the curriculum that Diagnoser covers does not comprehensively address the Singapore secondary school physics curriculum, and while the college/university level curriculum offers a closer match, implementing them in Singapore secondary schools would be difficult, given the conditions they require. For example, PI requires students to read and review textbook materials before coming to class. Such a practice would not be implementable in typical Singapore secondary schools, since the established practice has been for teachers to introduce new concepts to students. Hence, there clearly is room for a topic and concept agnostic physics intervention for secondary school students. Also, a topic and concept agnostic intervention is more 'portable' as it is not dependent on a specific curriculum in order for it to be relevant. Perhaps it is for this reason that ABPS has elements of PI and CGPS, while EPP has an element of CGPS.

Finally, it is interesting to note that assessment of almost all interventions included a satisfaction survey, in addition to pre/post testing and/or control/experimental group comparisons.

Table 3.5: Cross-intervention comparison of Interventions' "Content"

Intervention Name	Intervention Content	
	Key Topics & Concepts	Assessment
<i>Peer Instruction</i> (PI)	Topic and concept agnostic	Satisfaction surveys; Pre/Post Testing (Force-Concept Inventory (FCI) and other concept inventories); Control Group/Experiment Group comparison
<i>Cooperative Group Problem Solving</i> (CGPS)	Topic and concept agnostic	Satisfaction surveys; Pre/Post Testing (FCI); Control Group/Experiment Group comparison
<i>Tutorials in Introductory Physics</i> (TIIP)	Mechanics, electricity and magnetism, waves, optics, and thermodynamics	Satisfaction surveys; Pre/Post Testing (FCI)
<i>Activity-based Physics Suite</i> (ABPS)	Tutorials are based on <i>Tutorials in Introductory Physics</i> while laboratory sessions are based on templates covering mechanics, heat and thermodynamics, and electric circuits	Satisfaction surveys; Pre/Post Testing (Force-Concept Inventory (FCI) and other concept inventories); Control Group/Experiment Group comparison
<i>Andes Physics Tutoring System</i>	Mechanics, electricity and magnetism, optics	Satisfaction surveys; Control Group/Experiment Group comparison

(Andes)		
Diagnoser Project (Diagnoser)	Force and motion (mechanics), waves, properties of matter	Control Group/Experiment Group comparison
Extended Physics Program (EPP)	Topic and concept agnostic	Customised assessment includes enrolment figures, retention rates, satisfaction surveys, and comparison with non-"at-risk" students at the same University taking a 'normal' physics course

3.5 Reviewing Interventions' "Concept"

Based on the information summarised in Table 3.6, it is apparent that the college/university interventions that are non-ICT centred in nature (i.e. PI, CGPS, ABPS, TIIP, and EPP) prescribe activities that are based on the traditional triad of synchronised lectures, laboratories, and recitation sessions. Even PI, which focuses on peer discussion during lectures, acknowledges the role laboratory and recitation sessions play (see Crouch et al., 2007). Because the ICT-centred interventions address the *revision* aspects of physics education, the activities they prescribe are quite different from the non-ICT centred interventions. For example, students use Andes only after they have completed learning a specific, mathematical-based physics topic (such as Newtonian Mechanics). Andes serves as a 'homework assigner' and 'tutor' combined – it assigns pre-set questions from its database, and poses those questions for an individual student to solve. While solving questions within the Andes environment, the system forces students to solve any given problem in a logical, fine-grained, step-by-step manner, and offers feedback after every step. If the student needs assistance, pressing on a 'help' button would trigger a context-sensitive help feature, which provides varying amounts of help (from a simple hint to providing the entire problem-solving step required). The Andes system does not provide any feedback on students' performance to instructors, and is largely used as a standalone 'tutor' to help students improve their problem-solving skills.

With regards to Diagnoser (the only qualified intervention that targets secondary school students), students use the system as an individual formative assessment and feedback system. After being taught a particular topic in class, students access the Diagnoser system and answer a pre-defined 'Diagnoser Set' for that particular topic. This 'Diagnoser Set' is akin

to typical concept inventories like the FCI (see Hestenes et al., 1992). However, unlike concept inventories, feedback is provided to the students after every question answered. The feedback provided is meant to reinforce students' correct responses while offering alternate conceptions or suggestions for students to consider should they select an incorrect option. Unlike Andes, Diagnoser keeps a record of the students' response so as to provide teachers with a description of the problems students have, as 'diagnosed' by the students' responses. Also, the system can offer teachers with some advice for 'prescriptive activities' that may help students overcome their misconceptions/misunderstandings.

Looking at the non-ICT centred interventions, both PI and ABPS make use of ICT to some extent. However, the importance of using ICT is quite different for both these interventions – it is optional for PI, but critical for ABPS. For PI, Mazur (2009) pointed out that “it is not the technology but the pedagogy that matters” (p. 51). Indeed, this view is echoed by Lasry (2008), who found that “using PI with clickers does not provide any significant learning advantage over low-tech flashcards. PI is an approach that engages students and challenges them to commit to a point of view that they can defend. The pedagogy is not the technology by itself” (p. 244). For ABPS, due to its focus on “blend[ing] hands-on activities with reflection” (Redish, 2003, p. 182), the use of ICT is critical since “computer-assisted data acquisition [enables] students to collect high-quality data quickly and easily. This allows students to perform many experiments and to focus on phenomena rather than on data taking.” (ibid, p. 186).

It is apparent that the non-ICT centred interventions generally have a theoretical underpinning based on constructivism, whereas the ICT-centred interventions (i.e. Andes and Diagnoser) have a strong cognitive psychology underpinning. Indeed, Andes is based on “cognitive task analysis” (VanLehn et al., 2005, p. 2005) and helps build students' problem-solving skills by way of “the [small] grain size of Andes' interaction”, which “is a single step in solving the problem” (ibid). As for Diagnoser, Minstrell and colleagues (e.g. Hunt & Minstrell, 1994) stated that “[h]ow people learn physics is also an interesting question for cognitive psychology” (p.

51) and developed Diagnoser to “provide timely topic-relevant in-class assessment by way of computer-administered quizzes. The results of these assessments are both immediate and standard across classrooms” (Thissen-Roe et al., p. 239). For the ICT-centred interventions, ICT is essentially used to *replace* either the teacher (as in the case of Andes) or the media (as in the case of Diagnoser). In my opinion, using ICT as a 'replacement for teacher' has important implications. Firstly, from a social standpoint, it changes the educational landscape by placing computers at the foreground and teachers at the background of students' educational development. This leads to unwarranted beliefs about what computers can do for education, and creates unnecessary tensions between teachers and computers, as manifested in the following remarks:

Computer makes studying more student centered. When they use a computer to learn, they need to find and discover materials by themselves instead of teachers simply putting things, which are not always interesting into their brain...Teachers can use the computer to present concepts to students in ways that are much more engaging than the traditional way. As a teacher, don't you feel tired of standing in front of the blackboard and writing words on it?

- Dong Pan, 2000, ESL student (no attempts were made to correct the errors)
(taken from <http://kccesl.tripod.com/studentessays/computer.html>)

However, once again there are uninformed members of the general public who believe that they can really learn Spanish or French or Chinese or whatever through a computer program. I would hope that the writers of this software know that they are making false claims by saying that someone can become fluent by using it. But the people who buy the software don't know that -- they believe what they read, they spend their money on it, and that means they don't register for my class. That software could serve as a nice supplement to someone who is serious about learning a language, but it will never replace either classroom instruction or a cultural immersion experience.

I'm not REALLY worried that a computer will take away my job, but I am worried that the masses would like it to, just as the masses nowadays like everything that is faster, cheaper, and requires less thought and energy.

- Audrey, 2003, teacher

(taken from <http://board.jeffjsnider.com/viewtopic.php?p=21780&sid=606bb442fdb948d07257bb7e65fbbd0d>)

In my view, while learning from computers (in place of a teacher) may be effective and may be considered a legitimate form of learning, the community at large must recognise that computers are but one part of the larger process of enculturation (see Brown et al., 1989). Hence, when instructors or researchers design ICT-mediated interventions, they need to consider the wider learning processes and situate the interventions within its social context and practice. Student-centred learning does not mean teacher-absent learning, and a learning environment that is orchestrated by a teacher should not be synonymous with a teacher-centred focus to learning.

Secondly, from a financial standpoint, the creation of any 'artificial intelligence' (such as interactive learning courseware, video games, and interactive tutors) to replace a teacher are difficult to design, require specialised knowledge to code, and are generally expensive to create. At present, I am not sure if the cost justifies the results, especially when there are other more economical ways of utilising computer technology.

Thirdly, from a pedagogic standpoint, *learning directly from computers* has its groundings based in behaviourism. For example, it is still common to find generic multimedia courseware that are based on the principles of behaviourism (Herrington & Standen, 1999). Such instructions, whether computer-based or otherwise, are out-dated as they place too much emphasis on memory and recall, promoting rote learning that leads mainly to "inert knowledge" (Whitehead, 1929). Hence, it is often *caveat emptor* for consumers of such products.

From a 'replacement of medium' concept, Clark (1983, 1994) had established that media itself will not influence learning outcomes. Indeed, the activities performed by the Diagnostician –whether it is the provision of the question sets, or the assessment of students' answers, or the provision of feedback, or the suggestion of 'prescriptive activities' – may all be done via a paper-based system, albeit the speed will be much slower given the manual effort needed to record, analyse, reference and collate the generated data.

It is noteworthy that none of the interventions are based explicitly on a sociocultural perspective. Even PI, which implicitly draws on sociocultural theory, sees itself as being effective essentially because “[i]t continuously actively engages the minds of the students, and it provides frequent and continuous feedback (to both the students and the instructor) about the level of understanding of the subject being discussed” (Mazur, 2009, p. 51). In my opinion, PI's success may be seen from a sociocultural theory/activity theory perspective. From an activity theory perspective, PI changed the *objective* of the teaching practice, and as I have explained in Chapter Two, a change in an activity's objective necessitates a change in the activity itself. In the case of PI, the new activity focuses on students' conceptual understanding and as a result, students' conceptual understanding improves. After all, PI started only after Mazur found that his students could solve 'harder' problems involving multiple equations and variables but not 'simple' conceptual questions involving only the fundamental physics concepts because the students were memorising “learning 'recipes' or 'problem-solving strategies'...without considering the underlying concepts” (Mazur, 1997, p. 7). These problem-solving strategies had allowed his students to correctly solve numerous traditional physics questions (such as those involving physics formulas and mathematical calculations) in spite of serious misconceptions on the physics concepts involved in the question. As a result, there was an underlying change in the *objective* of Mazur's teaching practices. Hence, instead of (unknowingly) helping students to *memorise 'learning recipes'*, Mazur focused on building up his students' *conceptual understanding* of physics concepts, and this change in objective was reflected in his teaching practice as well as in his assessment of their learning (which includes classroom discussions and conceptual questions in

examinations). With regards to the no significant difference finding in learning outcomes regardless of whether high-tech clickers or low-tech flashcards are used, it is attributable to the fact that while the *material* artefact is different (i.e. clickers are physically different from flashcards), the *ideal* artefact is the same (i.e. both clickers and flashcards are used for the same purpose). Hence, no significant changes occurs as a result of changing the material artefact.

From a sociocultural theory perspective, students undergoing PI improved in their understanding of physics concepts due significantly to the peer *discussion* process. As Smith et al. (2009) reported,

Previous explanations for the value of PI have maintained the 'transmissionist' view that during discussion, students who know the right answer are explaining the correct reasoning to their less knowledgeable peers....Our findings that even students in naïve groups [where everyone in that group did not initially know the correct answer] improve their performance after discussion suggests a more [socio]constructivist explanation: that these students are arriving at conceptual understanding on their own, through the process of group discussion and debate. (p. 124)

In summary, as can be seen from the activities that were performed outside and inside of classrooms, educational practices were a direct reflection of (i) the objective of the educational process, (ii) the institutional and/or policy affordances and constraint, which provide for the various tools that were made available to teachers and students, and (iii) the underlying theoretical underpinnings of the intervention. For the ICT-centred interventions, students used ICT independently to build personal knowledge, while for the non ICT-centred interventions, ICT was used in-class in order to 'speed up' data processing. In other words, students in the interventions were learning *from* (e.g. Andes, Diagnoser) and learning *around* computers (e.g. PI, ABPS), but they were not learning *through* computers (e.g. Shahl, 2009), which in my opinion, are more supportive of learning from a sociocultural perspective.

Table 3.6: Cross-intervention comparison of Interventions' "Concept"

Intervention Name	Intervention Concept			
	Theoretical Underpinnings	Activities Outside of Classroom	Activities Inside of Classroom	Critical Pedagogical Concept
<i>Peer Instruction (PI)</i>	<p>Explicit: Constructivism</p> <p>Implicit: Sociocultural theory</p>	Students are required to read and review textbook materials before attending class	<p>There are slight variations to the PI process, but as described by Lasry et al. (2008):</p> <p>Lecturer gives a brief lecture (less than ten minutes) on the topic that students have reviewed on their own.</p> <p>Thereafter, the lecturer provides a ConcepTest, which is a short conceptual multiple-choice question on the subject being discussed (ConcepTest questions are very similar to questions posed in concept inventories, such as the FCI).</p> <p>Students are then given about one minute to individually think about the question, and are required to 'vote' for their answer by way of a show of hands, flashcards, or electronic clickers (i.e. audience response system).</p> <p>If less than 30% of students selected the correct answer, then the lecturer revisits the concept again, and provides another ConcepTest for students to individually assess and vote. If more than 70% of the students selected the correct answer, then the lecturer provides a brief explanation of the answer, and proceeds to give a brief lecture on the next topic (and the cycle repeats).</p> <p>Most of the time, between 30% to 70% of students would have selected the correct answer. In this case, the lecturer then asks the students to talk to their peers seated next to them and attempt to convince each other of their answer. The lecturer would also mingle with the students to have a sense of what they are saying, or assess if they have particular difficulties. After the peer discussion process (which would take several minutes), a new vote is taken and the process is repeated.</p>	Teaching by questioning
<i>Cooperative Group Problem Solving (CGPS)</i>	Explicit: Cognitive Apprenticeship/ Constructivism	Laboratory and recitation attendance required	<p>Based on a triad of synchronised lectures, laboratories, and recitation sessions.</p> <p>During lectures, lecturers introduce fundamental physics concepts taking into account typical students' preconceptions. They also model explicitly all of the problem-solving</p>	Leading students from an 'initial state' to a 'final state' via cognitive apprenticeship as a result of immersion in a

			<p>steps and decision processes required to solve the problem.</p> <p>During laboratory and recitation sessions, students work in small groups to solve word problems or experimental problems respectively. These sessions are coached by teaching assistants who are explicitly taught the cognitive apprenticeship process of coaching, scaffolding, and fading.</p>	“culture of expert practice”.
<i>Tutorials in Introductory Physics (TIIP)</i>	Explicit: Constructivism	Students are required to have attended the traditional lectures before attending class, and also have completed a pre-test on the topics to be solved during the recitation sessions.	<p>The recitation sessions are synchronised with the lectures.</p> <p>Students work in small groups during recitation sessions in order to solve the conceptual problems posed.</p> <p>Teaching assistants are on-hand to mentor students and lead them in the right direction and show them the significance of the problems to be solved (a process of guided inquiry).</p> <p>Thereafter, students are given 'homework' which are similar to the problems solved during the recitation sessions, after which they are required to take a post-test.</p>	Teaching by guided inquiry
<i>Activity-based Physics Suite (ABPS)</i>	Explicit: Constructivism	Laboratory and recitation attendance required	<p>Typically based on a triad of synchronised lectures, laboratories, and recitation sessions.</p> <p>Lectures are conducted via a interactive lecture demonstration (ILD) methodology, whereby students first make predictions (on a prescribed worksheet) on the experiment that the lecturer is to conduct. Thereafter, students summarise their observations on another prescribed worksheet. Demonstrations are based on common misconceptions, and aided by computers, projectors, and computer-based data loggers.</p> <p>Recitation sessions are based on TIIP, which have been described earlier.</p> <p>Laboratory sessions are based on RealTime Physics (RTP), which is designed to build understanding of fundamental concepts through use of a guided inquiry model with cognitive conflict. RTP relies heavily on computer-based data loggers.</p>	Students must be <i>actively doing physics</i> . Cognitive conflicts are resolved via an empirical approach.

			Also, homework and examinations are based on questions with 'open-ended' reasoning.	
<i>Andes Physics Tutoring System (Andes)</i>	Explicit: Cognitive Psychology	Students are to have learnt the concepts via self-study and/or attending of lectures before attempting the Andes system	Students independently use the Andes system as a 'homework problem' system. They attempt the questions on a computer with Andes installed, and using the Andes system, solve problems in a step-by-step manner as required by Andes. If the student needs help, the artificial intelligence provides the necessary assistance.	The small grain-size of interactions provided by the Andes system.
<i>Diagnoser Project (Diagnoser)</i>	Explicit: Cognitive Psychology	Students are to have learnt the concepts in class before attempting the Diagnoser system	Students independently use the Diagnoser system as a formative assessment system. They attempt the questions on a computer with Diagnoser running, and using the Daignoser system, obtain immediate feedback for the questions which they have answered. A teacher also has access to his/her students' response to the questions posed, and the Diagnoser system provides the teacher with suggestions for how to transform students' thinking by way of examples/counter-examples and/or empirical methods.	Immediate, well-directed feedback based on questions that addresses well known preconceptions
<i>Extended Physics Program (EPP)</i>	Explicit: Social Justice Implicit: Constructivism	Students must be pre-qualified to take the course Lecturers, course administrator and teaching assistants meet up once a week to discuss strategies for helping students who appear to be 'failing behind'	Based on a two-week synchronised cycle between lectures, group problem-solving workshops (recitation), qualitative minilabs, quantitative laboratories and review sessions on the same topic.	Extensive support for students, and small workshop and recitation sizes

3.6 Reviewing Interventions' "Consequence"

Based on the information summarised in Table 3.7, unlike the common consequences for students, there are some variations on the consequences for teachers. For example, when lecturers conduct PI (and when teaching assistants conduct TIIP), they are explicitly looking out to gain an improved understanding of their students' knowledge base and thought processes, whereas this explicit activity of uncovering students' knowledge base and thought processes is less apparent in CGPS and ABPS. For Andes, due to the absence of a feedback loop to teachers, it does not contribute to teachers' knowledge about their students in any significant manner. Hence, for students, Andes benefits them because it helps them to build up their problem-solving skills. Since the Andes system does not provide any feedback on students' performance to instructors, the main benefit for instructors is that it saves them time from having to assign 'homework' to students and individually working with each student. For Diagnoser, besides saving the teachers' time to assign formative assessment questions, the Diagnoser system also provides teachers with a record of their students' performance and a 'diagnosis' of their misconceptions.

Table 3.7: Cross-intervention comparison of Intervention "Consequence"

Intervention Name	Intervention Consequence		
	Students	Teachers	Other expected consequences
<i>Peer Instruction (PI)</i>	Improved learning outcomes; Increased satisfaction	Improved understanding of students' thought processes	None specified
<i>Cooperative Group Problem Solving (CGPS)</i>	Improved learning outcomes; Increased satisfaction	None specified	None specified
<i>Tutorials in Introductory Physics (TIIP)</i>	Improved learning outcomes; Increased satisfaction	Improved understanding of students' thought processes	None specified
<i>Activity-based Physics Suite (ABPS)</i>	Improved learning outcomes; Increased satisfaction	None specified	None specified
<i>Andes Physics Tutoring System (Andes)</i>	Improved learning outcomes; Increased satisfaction	No need to spend time assigning 'homework' and no need to individually tutor students	Technology used to improve students' learning outcomes without additional workload for teachers
<i>Diagnoser Project</i>	Improved learning outcomes	Improved understanding of	Technology used to improve

<i>(Diagnoser)</i>		students' preconceptions	students' learning outcomes without additional workload for teachers
<i>Extended Physics Program (EPP)</i>	Improved learning outcomes; Increased satisfaction	Improved understanding of students' difficulties and weakness	Equity for 'at-risk' students

3.7 Chapter Summary

In this chapter, I reviewed physics learning interventions that are in line with my own research interests. From a context perspective, my review shows that the vast majority of interventions targets college/university students when it is probably more important to improve physics teaching practices in secondary school classrooms. From a content perspective, the secondary school physics curriculum in Singapore is somewhat similar to the college/university curriculum in the USA (in which all the interventions were initiated from). However, it would be difficult to implement interventions targeted at a college/university level in a secondary school due to the unique affordances available in a varsity setting (such as the availability of teaching assistants and the ability to change assessment items). From a concept perspective, all the interventions have their theoretical underpinnings based on constructivism, and none have an explicitly sociocultural theoretical perspective. When ICT is used, its unique affordance to facilitate a new genre of communications was not exploited. From a consequence perspective, students' learning outcomes improved, and so did their satisfaction towards physics in general. From a teachers' perspective, some interventions explicitly create situations such that teachers would gain access to students' knowledge base and thought processes, whereas others are less explicit about this procedure.

A comparison of my intervention vis-a-vis the reviewed interventions will be made in Chapter Seven after I have discussed the results of students' (and teachers') immersion in my intervention.

CHAPTER FOUR

DESCRIPTION OF INTERVENTION AND RESEARCH DESIGN & METHODOLOGY

In this chapter, I describe how my physics revision intervention was designed based on the theoretical foundations expounded in Chapter Two. I start by providing the necessary background information on my place of research. Next, I explain the components of my intervention and thereafter describe the activities that go into each of the two unique processes that constitute the intervention. Thereafter, I provide a discussion on my research methodology and explain why design experiments (also termed design-based research) are appropriate, given my research questions, intentions, epistemological grounding, and theoretical perspectives.

4.1 Background

Given my interest in improving pedagogical practices in secondary school physics classrooms, I decided to approach my former secondary school (Bartley Secondary School in Singapore) to see if they were interested in being involved in this research project. I attended my secondary school education in Bartley from 1986 to 1989, and had conducted my MSc research (which may be considered as a feasibility study building up to this PhD research work) in the school from 07 July 2000 to 29 August 2000. However, no trace of my earlier work may be found in the school due to staff movement and poor dissemination of my research work then. I chose Bartley for two main reasons. Firstly, I had maintained a relationship with the school via its alumni network, and this relationship offered me access to the school's management team, including the Principal. Secondly, I wanted my intervention to be applicable to the vast majority of schools in Singapore, and given that Bartley may be considered as an average 'mainstream' secondary school provided with standard infrastructure and equipment (such as computers, classroom facilities, etc.), I believe that an intervention that 'worked' in Bartley would be appropriate for the majority of secondary schools in Singapore (for a discussion on the types of secondary schools in Singapore, see MOE, 2009).

Through the school's alumni network, I approached the school's Principal in January 2008 with a proposal to involve students in an intervention designed to help them revise physics concepts better. A presentation on the design rationale of the intervention was given to the Principal and Head of Department (HOD) for Science, and approval was given to involve a class of pure-physics (as compared to combined-science) students in the intervention. Collectively, we agreed that a small-scale study should be conducted (in October/November 2008; after the end of their school examinations) to gauge the overall effectiveness of the intervention prior to a full scale study involving an entire class for the academic year 2009 (from January to November 2009). Also, we decided that for the small-scale pilot study, the intervention would be evaluated primarily on the students' improvements in physics (as measured via pre/post intervention testing), and secondarily on the students' and their physics teacher's feedback on being involved in the intervention. The exact duration and scale of the main study would only be decided after the evaluation of the pilot study.

As there was only one class of students studying pure-physics who would be taking their GCE 'O' level examinations at the end of 2009, this class (4E1) was selected for involvement in our research study. 4E1 had a total of 23 pure-physics students (11 boys, 12 girls; mostly students with working-class parents) from a range of Asian countries: Singapore (9 pupils), Mainland China (4 pupils), Nepal (3 pupils), Thailand (3 pupils), Indonesia (1 pupil), Hong Kong (1 pupil), Myanmar (1 pupil) and Vietnam (1 pupil). The medium of instruction and assessment was English although the students are non-native speakers of the language. As of 31 Dec 2008, the students were aged between 15 and 17, and most students have been in the school since secondary one (January 2006). Historically, there has always been a greater number of foreign students in Bartley as compared to most other secondary schools in Singapore due to its close proximity to a Nepalese army camp. Nevertheless, foreign students are common in Singapore secondary schools, since more than one third of the country's total population is made up of foreign nationals. From a curriculum perspective, the students were taking physics GCE 'O' Level Syllabus 5058 and the curriculum covered Measurement,

Newtonian Mechanics, Thermal Physics, Waves, and Electricity and Magnetism. The curriculum was taught for about a year and one-half (from January 2008 to August 2009), after which the students took their GCE 'O' level examinations in October/November 2009. Their final physics grade for the GCE 'O' levels consisted of 30% for Paper 1 (MCQ questions), 50% for Paper 2 (short structured and open-ended questions), and 20% for a practical examination. All students took six other subjects (English language, mother tongue language (e.g. Chinese), mathematics (E), additional mathematics, chemistry, and combined-humanities) in addition to physics, with some students taking an additional subject (Higher Chinese).

Based on the last standardised national examination that 14 of the students took in 2005 (called the Primary School Leaving Examination, or PSLE for short), many of the students had just scored sufficiently to allow them admission into the GCE 'O' level programme. Out of a maximum aggregate score of 300, the students had an *average score* of 202 (top students typically score above 275, with the top score in 2005 being 282). The *cut-off score* for admission into the GCE 'O' level programme for the lower-tiered mainstream secondary schools is usually no less than 188, while the *average cut-off score* for admission into the GCE 'O' level programme taking into account all public secondary schools in Singapore for the 2009 cohort was 213 (see Appendix 4,1; the 2009 cohort PSLE scores were used because the 2005 cohort data is no longer available. However, these scores do not vary significantly). The 9 students who did not take the PSLE were foreign students who had passed the school's admission test and were directly admitted into the school's GCE 'O' level programme.

As of 31 December 2008, there were two teachers who were qualified and assigned to teach pure-physics in the school. One is the Head of Department for Science (Ms Er), who has about five years of experience teaching pure-physics. Ms Er has been with the school since her graduation from the Singapore National Institute of Education and in January 2008 was appointed as the Head of Department for Science. Another teacher (Mr Ng) had about three years of experience teaching pure-physics, and had been in the school for about six months (he left the teaching profession in June 2009).

While most interventions (including those reviewed in the previous chapter) often propose the application of a holistic (encompassing teaching, revision, testing and evaluation) intervention, I am reminded of the difficulty in changing established classroom practices, especially if information and communications technology (ICT) is to be introduced (e.g. Cuban, 1986; 2001). My experience tells me that teachers stay with tried-and-tested methods that allow them to cover the examination syllabus within an allocated time-frame. Hence, instead of designing a *teaching intervention* for physics education, I designed a *revision intervention*. From a dissemination perspective (especially based on Singapore's context), I believe that an intervention focusing on the *revision of taught content* has two distinct advantages over an intervention focusing on the *teaching of new content*. Firstly, teachers and students would be more willing to attempt a new practice that does not interfere with 'regular teaching hours'. Since physics revision lessons in Singapore are often conducted outside of standard curriculum time, a revision-based intervention would appear more palatable. Secondly, teachers and students would be more willing to attempt a new practice which does not differ too greatly from their established classroom practices (i.e. not beyond their 'collectivist' or 'societal' zone of proximal development; see Valsiner, 1988, p. 147). Since physics revision lessons in Singapore are already operating via group work and other more interactive methods, teachers and students would find dialogic and interactive practices (such as mine) more appropriate in a revision setting than in an authoritative teaching environment.

I am aware that *entry* into a school *does not imply access* into it (Ball, 1993), and studies involving a longitudinal design have generally more issues with access as compared to shorter studies (Cohen et al., 2000). Hence, to gain access into the school culture, I had based myself in that school throughout the study, and in my opinion, had employed common sense and good judgement in order to strike a balance between the demands of being a good researcher and responsible member of the school's community. Also, I was aware that as a former National University of Singapore post-graduate research scholar and current Cambridge University 'researcher', it was possible that my credentials could impress the Principal and teacher(s) into

accepting any of my suggestions. In addition, it is possible to suggest that any improvements made by the students were due mainly to *my presence*, rather than *my intervention*. I shall address each question in turn. On the issue of overawing the Principal and teacher(s), this did not happen as the school did not grant me permission immediately upon my request. In fact, I had to prepare a formal presentation and had to provide detailed explanations of my intervention programme and its expected outcomes before the Principal and HOD Science granted me permission. In addition, the Principal emphasised to me that while permission to conduct research in the school was granted, she or her teacher(s) reserved the right to withdraw from the research study, if either the teacher or the students perceived the study to be to their detriment. Hence, I believe the Principal and teacher(s) involved acted independently and objectively. As reported by them, the main reason why the Principal and HOD Science agreed to take part in this study was because they agreed, at least at the theoretical level, that my intervention could be useful for Physics revision, resulting in improved results for their students. In this sense, both the school and I were working towards the same goal. With regards to improvements resulting mainly due to my presence, this alternate explanation can be negated by the longitudinal nature of the study to minimise *novelty effects*. Ultimately, in line with the traditions of design experiments (see section 4.6), I am developing a profile that characterises the design in practice and, hence, in this dissertation, highlighted my involvement to the extent possible. In this way, a reader is made aware of the sociocultural forces at play in my intervention.

On the ethical front, even though I had the Principal's written permission, I also obtained a signed *voluntary informed consent* form from all the students involved. Because there is a possibility of embarrassment since students' misconceptions were exposed, students' names have been made *anonymous* in this final dissertation as well as in other related publications. Also, any student or teacher had a *right to withdraw* at any stage of the research project, and all the data collected from them would have been purged. Alternate (traditional) revision classes would have been arranged for students who have opted out. Prior to any video or audio recordings (e.g. during the focus group session of the pilot study), permission was first

sought. Also, since my intervention required students to use the computer and keyboard, I had ascertained that the students earmarked for involvement in this project were technically competent and, hence, no student was at a disadvantage.

4.2 Broad Intervention Design

Based on a sociocultural theoretical underpinning, the critical pedagogical concept of my intervention is promoting *meaningful talk*, both between students themselves as well as between teachers and students. In addition, I utilised ICT's unique affordances of enabling a *new communications genre* as well as its ability to *record discourse* in order to encourage and enhance the type of talk/discourse that takes place in a physics classroom. Broadly, given the centrality of addressing students' prior knowledge and the fundamental nature 'talk' plays in students' learning, I designed my revision intervention based on a cyclical process of computer-mediated *co-construction* and student-centric *prescriptive tutoring*.

During the co-construction phase, each student, working from their own individual computer, collaboratively solves physics questions with an anonymous partner through the computer via a text-chat and whiteboard facility. In other words, instead of learning *from* the computer (e.g. reading an 'e' textbook or using Andes to guide with individual problem-solving), students learn *through* it (i.e. by using the computer medium to work with other students). This computer-mediated collaborative problem solving process serves two purposes. Firstly, the text-chat and whiteboard logs (i.e. protocol data) allow a teacher to capture (and hence review at the teacher's convenience) students' knowledge negotiation and co-construction attempts *in situ*, which can be used for prescriptive tutoring later. Secondly, the discourse process itself promotes active intellectual involvement of the students by getting them to discuss and collaboratively solve physics problems posed. For example, by engaging in meaningful discourse, students may learn from each other via a Piagetian (e.g. Piaget, 1985) and/or Vygotskian (e.g. Vygotsky, 1978) account of cognitive development (conflict/coordination/resolution and the 'in two planes' theory). After all, from a sociocultural perspective, learning is a "social, communicative, and discursive process" which is "inexorably

grounded in talk" (Duffy & Cunningham, 1996, p.181).

During the prescriptive tutoring phase, a teacher analyses students' knowledge base and thought processes by reviewing saved copies of their text-chat and whiteboard logs, which have been transported through time and across space. The objective of this exercise is to identify misunderstandings and/or misconceptions that specific students have. Thereafter, the teacher provides revision lessons by prescriptively addressing students' physics concept misunderstandings as evident in the logs. Hence, revision lessons are primarily student-orientated and secondarily content-orientated, rather than the other way around. In other words, the focus is on the students and how they are thinking about the content (i.e. various physics concepts), instead of on the content and how the students should be thinking about them. As a revision intervention, this cycle between co-construction and prescriptive tutoring would start only after a particular topic had been taught in class.

4.3 Computer-mediated Collaborative Problem Solving Laboratory Sessions

4.3.1 Computer-mediated Collaborative Problem Solving (CMCPS) Set-up

There are four computer laboratories in the school, with each laboratory housing 40 PCs running Microsoft Windows XP operating system. Two labs house the newer and 'more stable' computers (see Figure 4.1), while another two labs house the older and 'mainly good for web-surfing' computers (see Figure 4.2). Every PC is connected to both the school's private Intranet, as well as the wider public Internet. As Microsoft NetMeeting comes pre-installed with the XP operating system, I used NetMeeting as the computer-mediated communications (CMC) software where students worked on collaborative problem solving. NetMeeting is an appropriate CMC software for my purpose because it features a shared whiteboard space and text-chat facility, has a user-friendly interface, and supports PPP (Point-to-Point Protocol), a TCP/IP-based protocol that does not require the use of a computer server. In addition, prior studies (Soong & Chee, 2000; Soong, 2001) have shown that NetMeeting is sufficiently feature-rich to allow for meaningful knowledge negotiation between students, and supportive of obtaining students' current knowledge and understanding in a 'naturally occurring' manner.



Figure 4.1: 'New' computer laboratory (notice the flat LCD monitors)

The NetMeeting CMC environment consists of a text-chat and a whiteboard facility (see Figure 4.3). The text-chat allows students to converse via typed text, while the shared whiteboard allows pictorial drawings and ideas to be depicted and discussed. During the CMCPS sessions, students were asked to regularly 'save' both the shared text-chat and the whiteboard onto a shared virtual disk, which was accessed at the end of the session for printing and analysis.



Figure 4.2: 'Old' computer laboratory (notice the CRT monitors)

Just prior to every computer-mediated collaborative problem-solving (CMCPS) session, I and/or the school's IT assistant would switch on the appropriate number of computers (e.g. seven in the pilot study, and 23 in the main study) and start up NetMeeting. We then assigned random 'nicknames' to each computer and randomly connected two computers together by means of NetMeeting's 'call' feature (see Figure 4.4). The 'new' computer laboratories had a classroom management software installed that allowed us to carry out these activities directly from our teacher's PC located at the front of the room (see Figure 4.5). Hence, this entire set-up process took no more than 20 minutes. I used random nicknames because I did not want students to know who their problem solving partners were. This approach to make anonymous the student pairs was intended to "reduce differences in social status and prestige, thereby providing a more egalitarian context for social interaction. This may lead to more open and spontaneous participation" (Jehng, 1999, p.675). When the students first got to the laboratory, they were handed a copy of the questions posed for that particular session. They would then select – from among the computers that were switched on – a computer that they wanted to work from, and then proceeded to collaboratively solve the given problems with their partner(s) via NetMeeting through the network. This random seat selection process further enhanced the anonymous configuration of our environment.

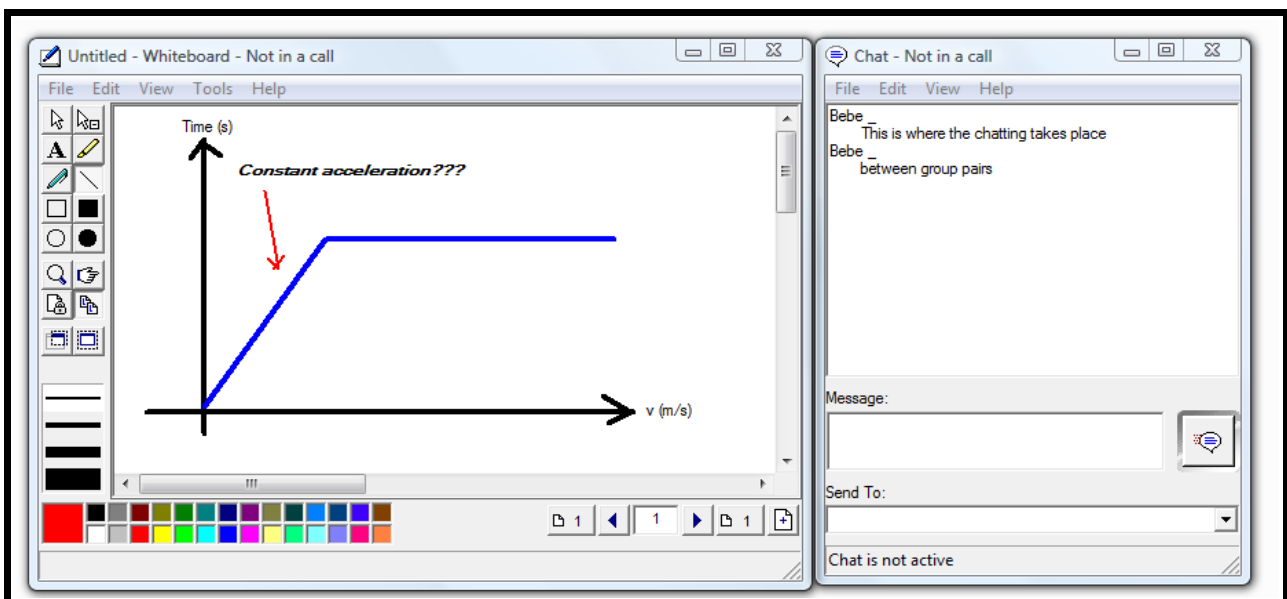


Figure 4.3: NetMeeting's whiteboard and text-chat feature

With respect to the formation of CMCPs teams, prior studies (e.g. Hung, 1996; Soong & Chee, 2000; Soong, 2001) revealed that grouping two students to form a problem solving team was optimal. However, in the event that there was an odd number of students, one group would consist of three students.

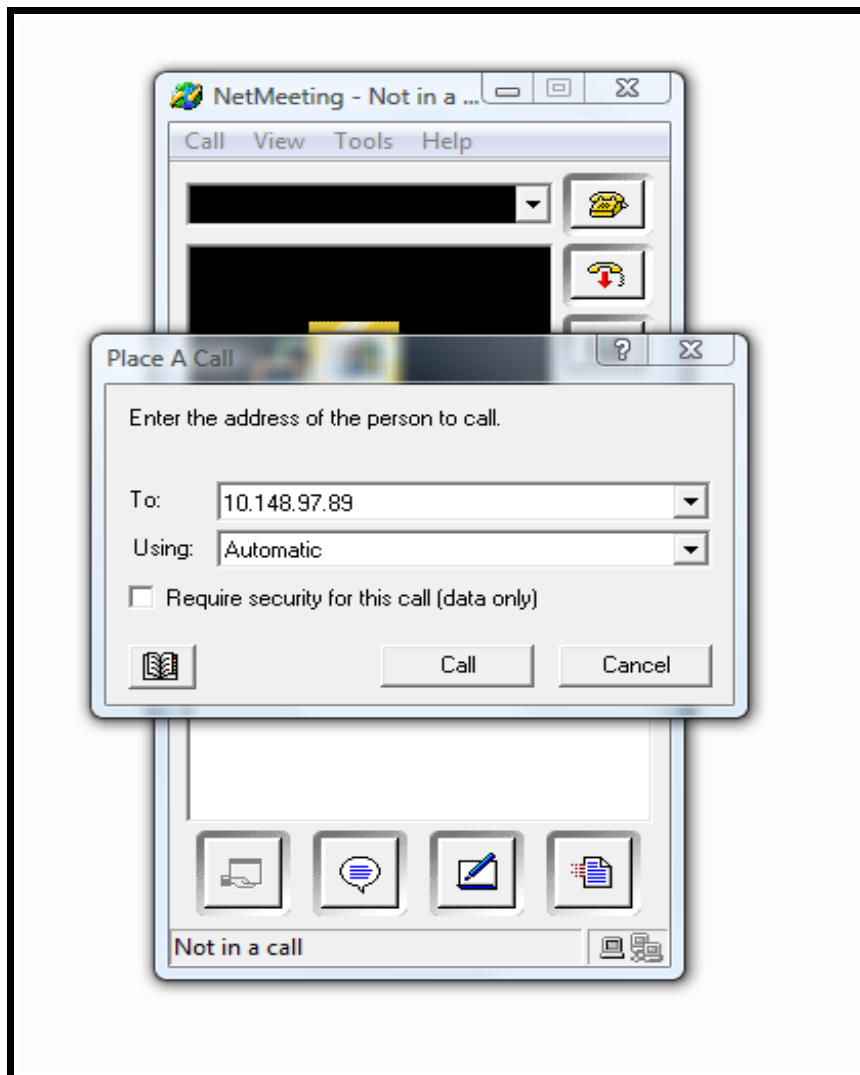


Figure 4.4: NetMeeting's 'call' feature (direct IP address calling; no server required)

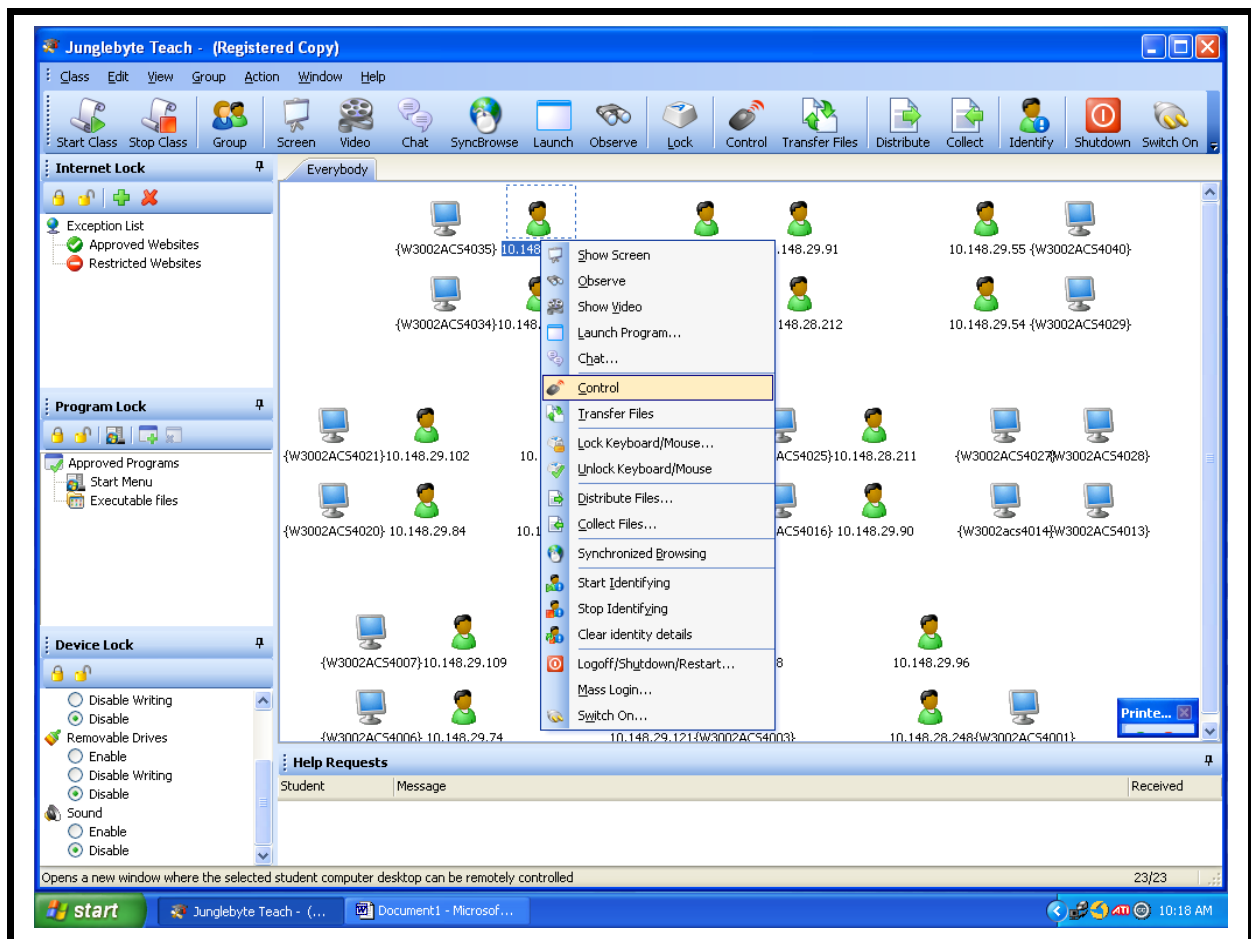


Figure 4.5: Classroom management system used to set-up computers in the lab

For all the initial CMCPs sessions, students were provided with a set of 'ground rules' for how they should behave during the session. This procedure was based on the findings of prior research that collaboration is most effective, and learning outcomes are maximised, if students jointly and explicitly subscribe to an appropriate set of interactional norms and goals (Mercer & Littleton, 2007). The ground rules (adapted from Mercer, 2000) were:

- They agree to share their ideas and listen to each other, no matter how silly it might appear
- They agree to consider what their partner(s) has written or drawn
- They agree to respect each other's opinions
- They agree to give reasons for their ideas
- They agree to express their ideas and workings neatly and clearly
- If they disagree with each other, they will ask "why?" or provide reasons for their

disagreement

- They agree to discuss only on the questions posed (e.g. no asking who their partner is)
- They agree to only work on solving the problems (e.g. no web-surfing)
- They agree to try to concur on a solution, prior to asking the teacher(s) to check their answer

Throughout the entire (pilot and main) research study, I found that the students generally followed the ground rules during the CMCPs sessions. On occasions, there were very minor disruptive behaviour exhibited (e.g. asking for the identity of their partner, guessing the identify of the partner, random drawings on the whiteboard), but because I (and/or the teacher during the main study) was in the laboratory overlooking what the students were doing, such behaviours were kept to a minimum. In addition, the students were constantly reminded that every message sent to their partner would be recorded in the log, and hence the source of disruptions would be traceable. Such actions helped to keep disruptions at bay.

4.3.2 CMCPs: Questions Posed

I had initially wanted to base the questions posed to the students on "concept rich problems" (e.g. see Heller & Heller, 1999a). I believe that such problems tend to be more authentic as they attempt to draw on students' previous experience and/or how they relate to everyday situations. Hence, they can help students relate Physics concepts to real experiences, thereby allowing them to talk more freely about their preconceptions. However, the physics teachers in the school commented that concept rich problems are fundamentally different from the types of questions posed in the GCE 'O' level examinations and, hence, the questions that we (the physics teacher and I) posed during the CMCPs sessions were a mixture of concept rich (e.g. see Figure 4.6) and traditional (e.g. see Figure 4.7) questions.

Joe was lying straight on the floor when a boy on a bicycle (total mass = 40kg) rolled over his legs. This was immediately followed by a man on a motorcycle (total mass = 120kg). Fortunately, Joe is fine, and said that the pain caused by the bicycle is the same as the pain caused by the motorcycle. Is this possible? Explain your answer. [3]

Figure 4.6: Example of a concept rich physics problem (from the topic, pressure)

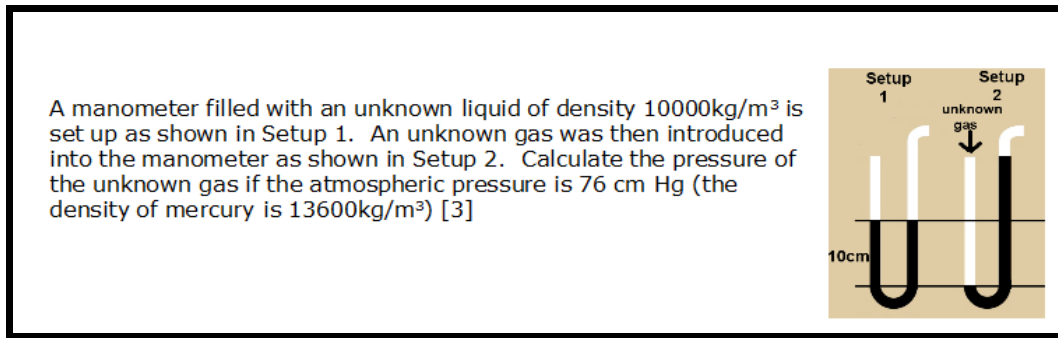


Figure 4.7: Example of a traditional physics problem (from the topic, pressure)

4.3.3 CMCPs: Student, Teacher, and Computer Laboratory Assistant Training

From a technical perspective, the CMCPs sessions basically involved students typing in the text-chat window with a keyboard and drawing on the whiteboard with a mouse. Hence, the students involved in this research study were already familiar with such basic computer operations, and no technical training was required. The only 'training' I provided the students is what I term as 'activity objective' training, whereby I explained to the students the objective of them working on problem solving with a partner via the CMC environment, and emphasised what they needed to do during the CMCPs sessions. Broadly, I explained to them that they were working on collaborative problem solving with a partner via a computer-mediated environment because the environment offered them:

- The possibility to learn from one another, where learning might take place natively via a Piagetian (conflict/coordination/resolution) or Vygotskian (ZPD) effect
- The confidence to freely and fully discuss their preconceptions and ideas, given that their identities were made anonymous and their teacher would review their articulations and provide them with instruction that is specifically targeted at correcting their misconceptions or misunderstandings

From a teacher's perspective, I had informed the teachers that the objective of the CMCPs session was for students to work with their partners via the CMC environment. Hence, as far as possible, all students' comments should be articulated between the students via the network so that their problem solving attempts are recorded and made available for review. Therefore,

it was important for teachers to let students 'struggle' and make mistakes, and hold off providing students with hints for as long as possible. Generally, students discussed with their partners and only called for the teacher when both parties have agreed on a specific solution. The teacher would then check the solution by reviewing appropriate discourse as highlighted by the students in the text-chat box (or the whiteboard). Naturally, because the teacher could only be at one place at any time, only one student would call for the teacher, and this could suggest to the students who their partner was. However, it is our (the physics teacher and my) opinion that after working with each other for a while, students were not very interested in knowing the identity of their partners. If the students' solution was correct, the students were told that they were correct and told to proceed to the next problem. If the students' solution was incorrect, this was also related to the students, and it was up to the teacher to provide hints if it was deemed necessary. If the students' solution was still incorrect after numerous attempts, they were told to skip that question and attempt the next. By and large, *no solutions were provided during the CMCPs sessions, as it was a time meant for student discourse, and not teacher instruction.* Figure 4.8 provides a summary of a CMCPs session.

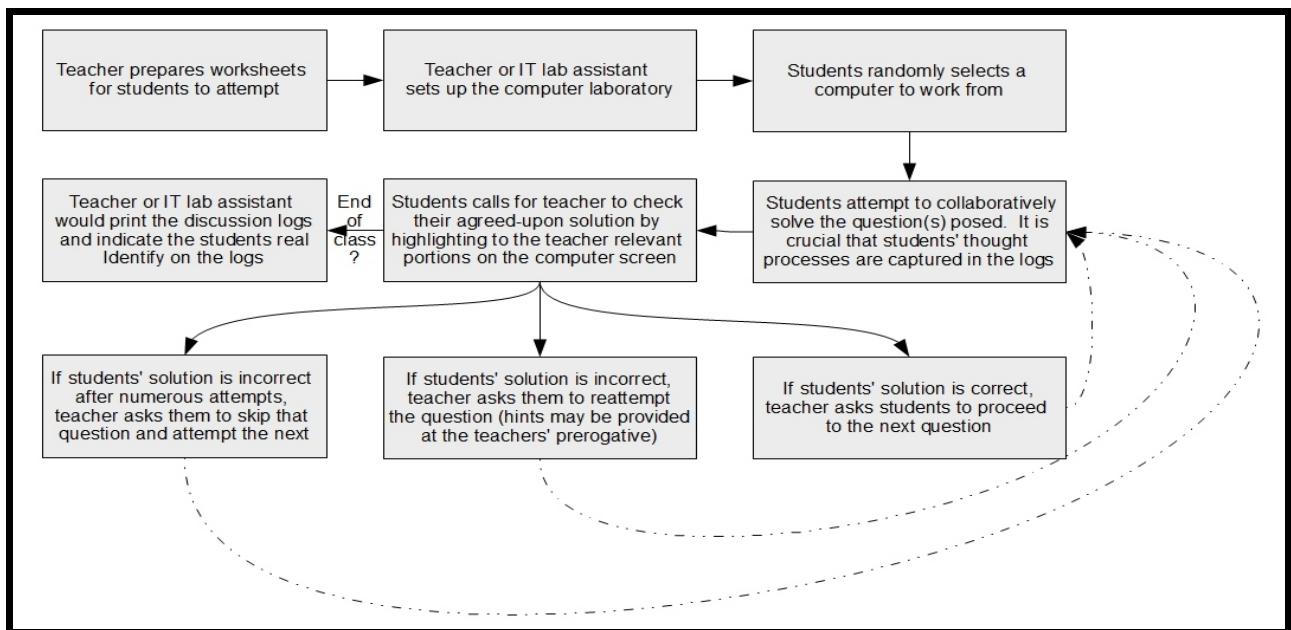


Figure 4.8: Summary of a CMCPs session

From an IT lab assistant's perspective, no training was required as the set-up of the computer laboratory was very straight-forward. The IT lab assistant had observed how I set-up the lab

and was able to repeat the procedure without difficulty on subsequent occasions. Generally, all that was required was for the assistant to set-up the computers, and when the students had left the laboratory, to print out the logs. Since students completed a short survey after every CMCPs session in which they had to write down their name and 'nickname' used for that particular CMCPs session, the IT lab assistant could indicate on the logs who the students were. This identification exercise was used to allow teachers to know which students had said what.

4.4 Prescriptive Tutoring Classroom Sessions

Based on Mortimer and Scott's treatise on meaning making in secondary science classrooms, there are six main teaching interventions in secondary science classrooms (see Table 4.1). The "first three [teaching interventions] relate to how the teacher act to introduce and develop the scientific story and the remainder [three teaching interventions] refer to other aspects of staging the teaching performance" (2003, p. 45).

Table 4.1: Secondary science teaching interventions (Mortimer & Scott, 2003, p.45)

<i>Teacher intervention</i>	<i>Focus</i>	<i>Action the teacher might take</i>
1. Shaping ideas	Working on ideas, developing the scientific story	Introduce a new term; paraphrase a student's response; differentiate between ideas
2. Selecting ideas	Working on ideas, developing the scientific story	Focus attention on a particular student response; overlook a student response
3. Marking key ideas	Working on ideas, developing the scientific story	Repeating an idea; ask a student to repeat an idea; enact a confirmatory exchange with a student; use a particular intonation of voice
4. Sharing ideas	Making ideas available to <i>all</i> the students in a class	Share individual student ideas with the whole class; share group findings; ask students to prepare posters summarising their views
5. Checking student understanding	Probing specific student meanings	Ask for clarification of student ideas; ask students to write down an explanation; check consensus in the class about certain ideas
6. Reviewing	Returning to and going over ideas	Summarise the findings from a particular experiment; recap on the activities of the

		previous lesson; review progress with the scientific story so far
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Mortimer and Scott also introduced four different communicative approaches (see Table 4.2) based “on a continuum between *interactive* and *non-interactive* talk on the one hand, and between *dialogic* and *authoritative* talk on the other.” (ibid, p.34; emphasis in original).

Table 4.2: Four classes of communicative approach (Mortimer & Scott, 2003, p.35)

Interactive / Dialogic	Non-Interactive / Dialogic
Interactive / Authoritative	Non-Interactive / Authoritative

Using their teaching intervention and communicative approach models, our prescriptive tutoring lesson flow was as depicted in Figure 4.9. Nonetheless, teaching is a dynamic process and there were times when our lessons did not follow the six steps to the letter. However, as far as possible, we tried to follow these six steps, as we believed following the sequence would help our students learn better, since the six steps allowed us to focus on helping students to understand the concepts discussed, rather than on getting the correct answer to the question posed. *In other words, the objective of a prescriptive tutoring session was to ensure that students understood the concepts being discussed; the objective was not to ensure that students knew how to arrive at the right solution.*

During the prescriptive tutoring session, the basis for instruction primarily came from students’ protocol data, rather than a pre-specified timetable. In other words, the session would always start with, and revolve around, the students’ mental models. For example, if analysis of the students’ protocol data revealed that they had misconceptions with a particular aspect of Newton's Third Law of Motion, then we would start by selecting that particular misconception for discussion. Students were shown the question that was asked during the CMCPs session,

as well as the protocol data of students' collaborative problem solving efforts which revealed the misconception. We then asked students to comment on the question posed (e.g. was it easy, hard, or just tricky? Was the question difficult to understand? What broadly was the understanding of this topic?). We then shaped students' ideas by explaining to them what the normative views were, and what their misconception implied. Thereafter, we checked students' understanding by getting them to articulate, in their own words, what the normative

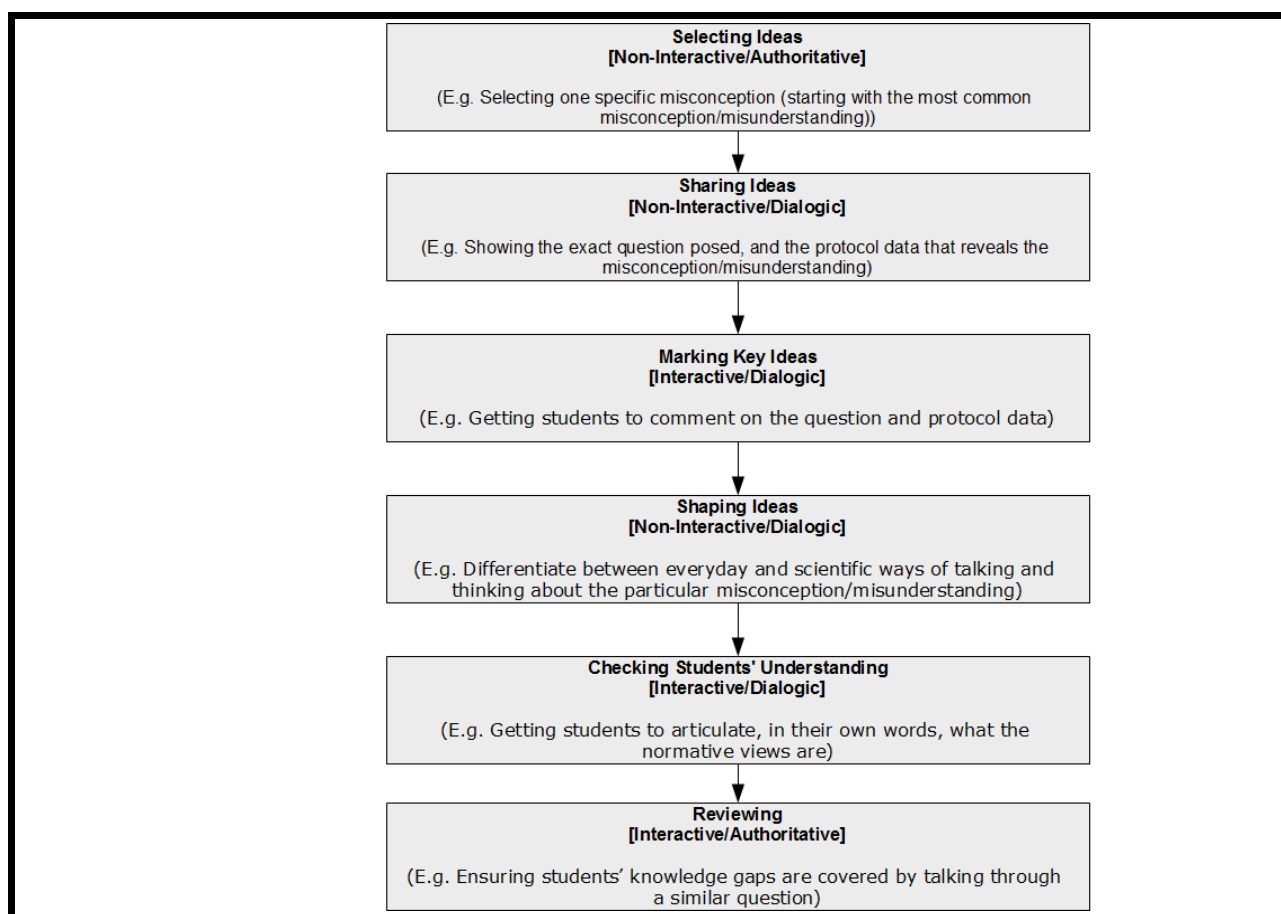


Figure 4.9: Prescriptive tutoring lesson flow

views are, and why their preconceptions were incorrect. Thereafter, to ensure students understood the lesson, we reviewed the topic by getting the students to answer a question (similar to the one which led to exposure of the misconception). Once we were satisfied that the students' thinking had been transformed, we repeated these six "teaching interventions" in their respective order until all misconceptions/misunderstandings had been addressed. Naturally, attempting to change students' preconceptions was a difficult process and a highly

situated activity, and even at the end of the session, we could not be entirely sure that they were entirely convinced by our explanations. Nonetheless, because we knew exactly where our students' difficulties lay, we had at least taken the first step in leading them towards the normative views.

4.5 Analysis from an Activity Theory Perspective

From an activity theory perspective, the intervention I have designed has two features that would necessarily change the sociocultural practice of classroom physics revision. Firstly, the intervention changed the *objective* of the classroom revision sessions. In the past, the teacher's objective of conducting revision sessions was to ensure that students could answer the questions posed (see Chapter Six). However, the intervention showed that getting a correct answer did not necessarily mean that students understood the concepts involved, and highlighted the importance of getting students to understand the concepts relevant in the questions posed. Hence, the objective changed from '*getting the correct answers to the questions posed*' to '*understanding the physics concepts in the questions posed*'. As discussed in Chapter Two, *a change in an activity's objective necessitates a change in the activity itself*. Hence, classroom revision sessions via the intervention was a fundamentally different classroom practice as compared to traditional revision practices. Secondly, the introduction of ICT as an artefact that allowed *all* the students to simultaneously problem solve with each other while still allowing the teacher to have deep insights into *all* the students' thought processes and knowledge base resulted in the affordance for the conduct of a *new activity* (i.e. prescriptive tutoring) which was not feasible in the past. This is because, from an *ideal* (as opposed to *material*) perspective, ICT is now being used to *support and record discourse* in a manner that makes it feasible for teachers to gain deep insights into how students are thinking. Hence, it can be seen how the consideration of sociocultural theory and activity theory informed the design of my intervention.

Shown in Figures 4.10 and 4.11 are instantiations of the activity theory constructs depicting the pre-intervention and intervention activities respectively, where it can be seen that these

were vastly different activities despite the majority of constructs being similar. The pre-intervention objective was to ensure that *students could answer the questions posed*. Consequently, the division of labour was such that during revision, the students focused on answering numerous questions from past year examination papers, while the teacher focused on showing students how the correct answers were arrived at. It can also be seen that the artefacts that mediated this activity were identical to those used in their examinations, such as the GCE 'O' level examinations.

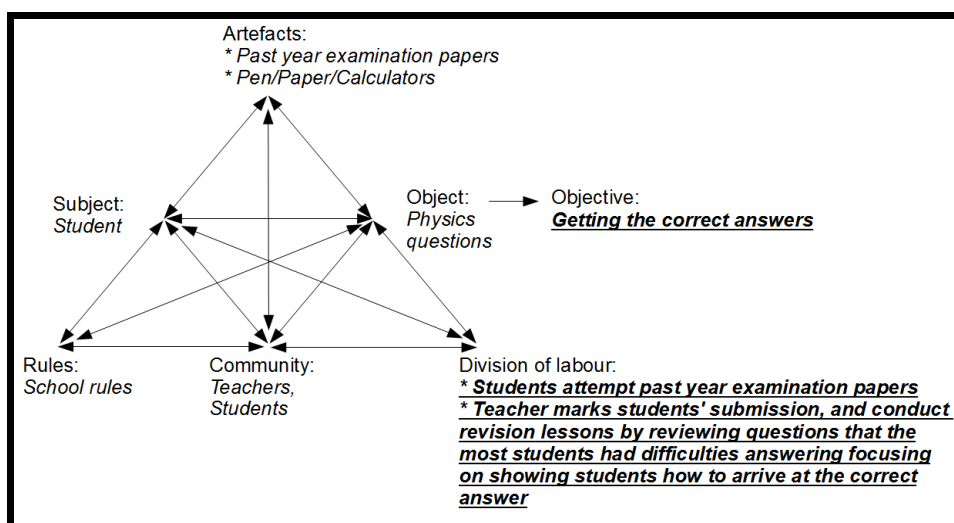


Figure 4.10: Activity Theory constructs depicting the 'getting the correct answers to the questions posed' activity

The activities inherent in the intervention were fundamentally different from the pre-intervention revision activities primarily because of a difference in objective, which was afforded by ICT. Our key objective of the intervention was to ensure that students *understood the physics concepts posed in the questions*. In order to help the students understand the relevant physics concepts, we needed access into the students' thought processes and knowledge base, and this was mediated by ICT. Consequently, the division of labour was such that the students used the computer-mediated 'text-chat' and whiteboard tool for peer discussion such that their thought processes and knowledge base were made overt for our review and analysis, thereby allowing us to prescriptively focus on specific physics concepts that students needed additional support in. Therefore, with the introduction of the

intervention, the sociocultural practice for physics revision had changed, and as I have presented in Chapter Two, the change in sociocultural practices led to changes in how students related to physics (see Chapter Six).

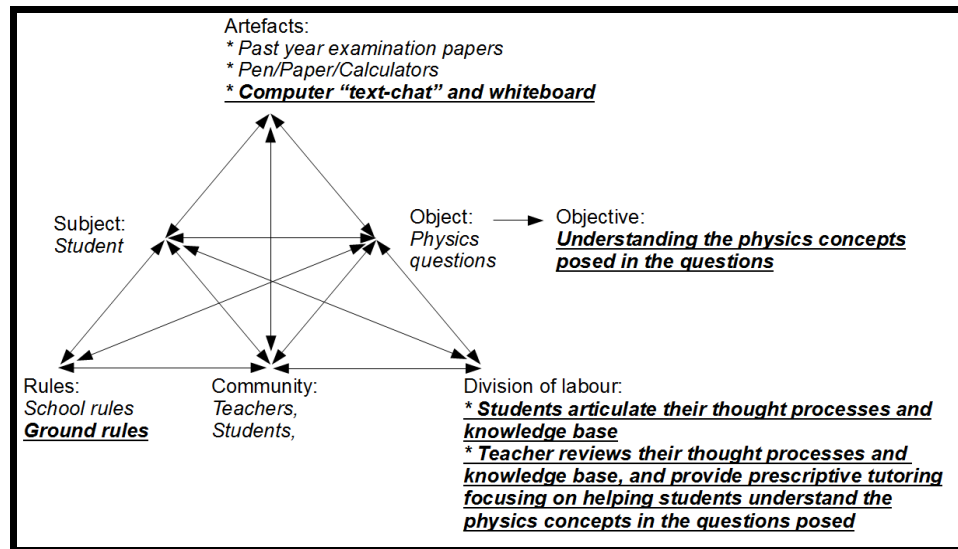


Figure 4.11: Activity Theory constructs depicting the 'understanding the physics concepts posed in the questions' activity

4.6 Design-based Research (DBR) Methodology

My proposed study follows a long tradition of classroom-based intervention research investigations (e.g. Palinscar, 1982; Palinscar & Brown, 1984; Heller & Heller, 1999a). However, while the design and study of learning interventions have a long tradition in educational research, Wells (1999) warns of 'intervention studies' where,

an attempt is made to introduce some new curriculum materials or an improved approach to pedagogy or classroom management that has been developed by “experts” outside the classroom. In this tradition, the emphasis is on making changes to what *is* in order to achieve what *ought* to be the case – according to the beliefs and values of the originator of the change. However, this is equally unsatisfactory. For although there is a strong commitment to bring about improvement, two essential ingredients are missing: first, the grounding of change in the specific cultural and historical context

of the classrooms involved and, second, the active participation of the individual teachers concerned in deciding what sort of changes to make and how best to try to make them (p.xiv; emphasis in original).

Wells, a very experienced applied educational researcher, reminds me that I need an appropriate research methodology that is able to address change which is grounded in the situated context of the classroom, as well as ensure the active participation of the teachers involved. Towards this end, the research methodology I used for my study follows on the tradition of *design experiments* pioneered by the late Ann Brown (for e.g. of design experiments, see Palincsar & Brown, 1984; De Corte et al., 2001; Angeli & Valanides, 2005; Kafai, 2005). In addition to being an intervention-based methodology, design experiments also take into account the missing “two essential ingredients” highlighted by Wells (since, like Wells, Palincsar and Brown also subscribe to sociocultural theory; see Palincsar, 1998). Also known as design-based research (see Barab & Squire, 2004; for more detailed discussions on design experiments, refer to the Theme Issue of *Educational Researcher*, 2003, 32(1), the Special Issue of *The Journal of the Learning Sciences*, 2004, 13(1)), and the Special Issue of *Educational Psychologist*, 2004, 39(4)). Brown (1992) explained that design experiments are modelled “on the procedures of design sciences such as aeronautics and artificial intelligence”, with educational design scientists attempting “to engineer innovative educational environments and simultaneously conduct experimental studies of those innovations” (p.141). In contrast, whereas “the natural sciences are concerned with how things work and how they may be explained” (Gorard et al., 2004, p.578) and the social sciences are interested in “material reality insofar as it plays a direct or indirect part in social action”, (Alasuutari, 2004, p.3), “design sciences are more concerned with producing and improving artefacts or designed interventions, and establishing how they behave under different conditions” (Gorard et al., 2004, p.578; see also Collins et al., 2004). Additionally, Amiel and Reeves (2008) perceive that “traditional predictive research in educational technologies has...offered little systematic advice to the practitioner...[whereas] design-based research provides an innovative proposal for *research on innovation and education*” (p. 30; emphasis added).

4.7 Comparing DBR to Psychological Experiments & Ethnography

In order to delineate design experiments as a research methodology suitable for my research questions and intentions, I contrast it as a distinct methodology vis-à-vis a methodology that typifies a natural science methodology (i.e. psychological experimentation) and a social science methodology (i.e. ethnography). Adapting a framework from Barab and Squire (2004), which compared psychological experimentation and design-based research methods, I compare these methodologies' (i) location of research, (ii) complexity of variables, (iii) focus of research, (iv) role of participants, (v) unfolding of procedures, (vi) iteration extent, (vii) amount of social interaction, and (viii) characterisation of findings.

4.7.1 Location of Research

For design experiments, the main research study occurs mainly in real-life settings (such as real-world classrooms). It is possible that a controlled laboratory setting might be used to test out an initial 'test treatment', but eventually all such test treatments will be implemented and evaluated in a real-world setting. On the other hand, research work for psychological experimentation mainly occurs in controlled settings, such as a laboratory specially set-up for a particular experiment. For ethnography, the research study occurs almost exclusively in real-world settings, especially in communities of interest.

4.7.2 Complexity of Variables

Design experiments involve the study of multiple dependent variables, including climate (e.g. available resources), outcome (e.g. learning content) and system (e.g. dissemination) variables. There is no intention to 'control for' specific variables, but rather, the focus is on providing an account of all the relevant variables in play. On the other hand, psychological experimentation frequently involves the study of a single or couple of dependent variables, and how it is correlated or directly affected by other independent variables. Ethnography, like design experiments, involves the study of multiple variables. However, the classification of these variables is typically of lesser importance as compared to design experiments.

4.7.3 Focus of Research

For design experiments, the focus of the research is on characterising the situation in all its complexity, with a goal of bringing out change and improvements that are readily transferable to other similar real-world settings (e.g. from one academically average secondary school in Singapore to the next). For psychological experimentation, the focus of the research is usually on identifying a few variables and holding them constant so as to uncover casual relationships between dependent and independent variables (e.g. how the lack of sleep (negatively) affects students' test performance). Ethnography focuses on characterising the situation in all its complexity, with a goal of describing particular areas of interest via "thick descriptions" (see Geertz, 1973, chapter one).

4.7.4 Role of Participants

In design experiments, different participants could be involved in different stages of the design experiments. For example, teachers could be involved at the initial *design* phase, while both teachers and students could be involved during the main *evaluation* phase. However, what is important to highlight is that in design experiments, the participants are involved not merely as passive test subjects, but rather as active participants who contribute to the research process (e.g. by suggesting areas of improvements). For psychological experimentation, participants are strictly treated as test subjects, and have no direct input on the research process other than performing the tasks expected of them. As for ethnography, participants are usually specific individuals with specific stories to tell. Indeed, a 'participant' in the research may even be non-human (e.g. a cock in a Balinese cock-fighting community; see Geertz, 1973, chapter 15), even though it is always through human-beings that stories are told.

4.7.5 Unfolding of Procedures

Design experiments start with a framework and general process methodology, but involves flexibility in design revisions depending on their success in practice and in consultation with the

participants. On the other hand, psychological experimentation uses a fixed procedure, in which every subject is expected to be given the same experimental treatment. As for ethnography, no specific procedures are to be followed (although there may be general guidelines) as it is part of a naturalistic study of a specific culture.

4.7.6 Iteration Extent

Design experiments are highly iterative, as they involve both theory building and experimentation at the same time. On the other hand, psychological experimentation uses fixed procedures in order to 'control for' differences in the climate or system variables. For ethnography, there is no iteration as the research study is meant to be an in-depth study of a particular culture as its people lives their daily life.

4.7.7 Amount of Social Interaction

In design experiments, the social interaction between the actors in the research setting is frequent and complex. For example, if the research setting is in a regular classroom, then the researcher, teacher, and students would be in frequent contact involving complex interactions. On the other hand, psychological experimentation isolates the subjects in order to control (or minimise) interactions, thereby reducing 'noise'. For ethnography, there are complex social interactions between actors in the research system, and the researcher will often have to be an 'insider' in order to have access into the nuances of the culture under study.

4.7.8 Characterisation of Findings

Design experiments looks at multiple aspects of the design in the research setting, and seeks to develop a framework/profile that characterises the design in practice. Psychological experimentation focuses on testing hypotheses, while ethnography focuses on writing thick descriptions of multiple accounts of the same culture as experienced by different individuals within the community.

In short, design experiments occur mainly in real-life settings (e.g. in regular classrooms),

involving the study of multiple variables (e.g. students' test scores, students' classroom learning interactions). Instead of attempting to 'control for' independent variables, it focuses on characterising the situation in all its complexity. Participants (e.g. teachers, students) are involved not merely as participants to be studied or manipulated, but as stakeholders who are able to influence the small, iterative changes of the environment studied. It also takes into account the complex social interactions between the participants themselves, and also with the researcher. In addition, it involves looking at multiple aspects of the design in order to develop a profile that characterises the design in practice. Hence, given its sensitivity to "the specific cultural and historical context of the classrooms involved" and "the active participation of the individual teachers" and students "concerned in deciding what sort of changes to make and how best to try to make them", design experiments, as a research methodology, address the two key ingredients Wells discussed about as being missing in typical intervention studies, and is entirely appropriate given my research objectives. Table 4.3 provides a summarised table of the comparisons described.

4.8 Chapter Summary

The first part of this chapter provided a description of my intervention, which is summarised in Figure 4.12. Broadly, the intervention is based on a mutually reinforcing cycle of CMCPs and PT sessions. After a topic has been taught in class, students are scheduled to go to a computer laboratory in order to solve physics questions (on the topic recently taught) with an anonymous partner. All discourse and problem solving attempts between student pairs are mediated by a whiteboard and text-chat facility, which is provided by a CMC software. During the CMCPs sessions, students may learn from both a Piagetian (conflict/coordination/resolution) as well as a Vygotskian (ZPD) account of cognitive development. There is a possibility that students may confuse each other, but because the students' discourse are mediated by the CMC software, their protocol data are recorded and, hence, transportable across space and through time. With the logs printed, their teacher would then review and analyse the students' problem solving attempts in order to identify misconceptions, misunderstandings, knowledge gaps, or generally identify specific areas that

Table 4.3: Comparing psychological experimentation, ethnography, and design-based research (adapted and extended from Barab & Squire, 2004, p.4)

Category	Psychological Experimentation	Ethnography	Design Experiments/Design-based Research
Location of research	Conducted in controlled (e.g. laboratory) settings	Occurs mainly in real-life (e.g. classroom) settings	Occurs mainly in real-life (e.g. classroom) settings
Complexity of variables	Frequently involves a single or a couple of dependent variable	Involves multiple variables, including climate (e.g. available resources), outcome (e.g. learning of content) and system (dissemination) variables	Involves multiple dependent variables, including climate (e.g. available resources), outcome (e.g. learning of content) and system (dissemination) variables
Focus of research	Focuses on identifying a few variables and holding them constant so as to uncover casual relationships	Focuses on characterising the situation in all its complexity, with a goal of describing particular areas of interest	Focuses on characterising the situation in all its complexity, with a goal of bringing about change and improvements
Role of participants	Treats participants as subjects	Participants are specific individuals with specific stories to share	Involves different participants in different stages of the design experiment (e.g. teachers in the initial design; teachers and students <i>in situ</i>)
Unfolding of procedures	Uses fixed procedures	No specific procedures are to be followed, as it is part of a naturalistic study of culture	Starts with a framework, but involves flexibility design revisions depending on their success in practice in consultation with the participants
Iteration extent	The fixed procedures are usually repeated for different subjects	No 'iteration' as it is a in-depth study of a particular culture	Highly iterative process involving input from the same participants
Amount of social interaction	Isolates learners to control interaction	Complex social interactions between actors in the system (e.g. students, teachers, researchers, etc.)	Frequently involves complex social interactions between actors in the system (e.g. students, teachers, researchers, etc.)
Characterising the findings	Focuses on testing hypothesis	Involves writing a thick descriptive of multiple accounts of the same culture as experienced by different individuals	Involves looking at multiple aspects of the design and developing a profile that characterises the design in practice

need additional scaffolding. During the PT sessions, the teacher focuses on what the students drew and wrote, instead of the content which the students are meant to learn. Through a six-step teaching sequence, students are slowly led to the normative views while taking into account their misconceptions/misunderstandings. In my opinion, this secondary school physics revision intervention fills a gap in current physics education research, which has thus far focused its attention on designing physics learning interventions for college/university level students. Additionally, the intervention utilises two unique affordances of ICT – the enabling of a new communications genre, and its ability to record discourse for subsequent review and analysis. A further account of the intervention 'in action' is given in Chapters Five and Six.

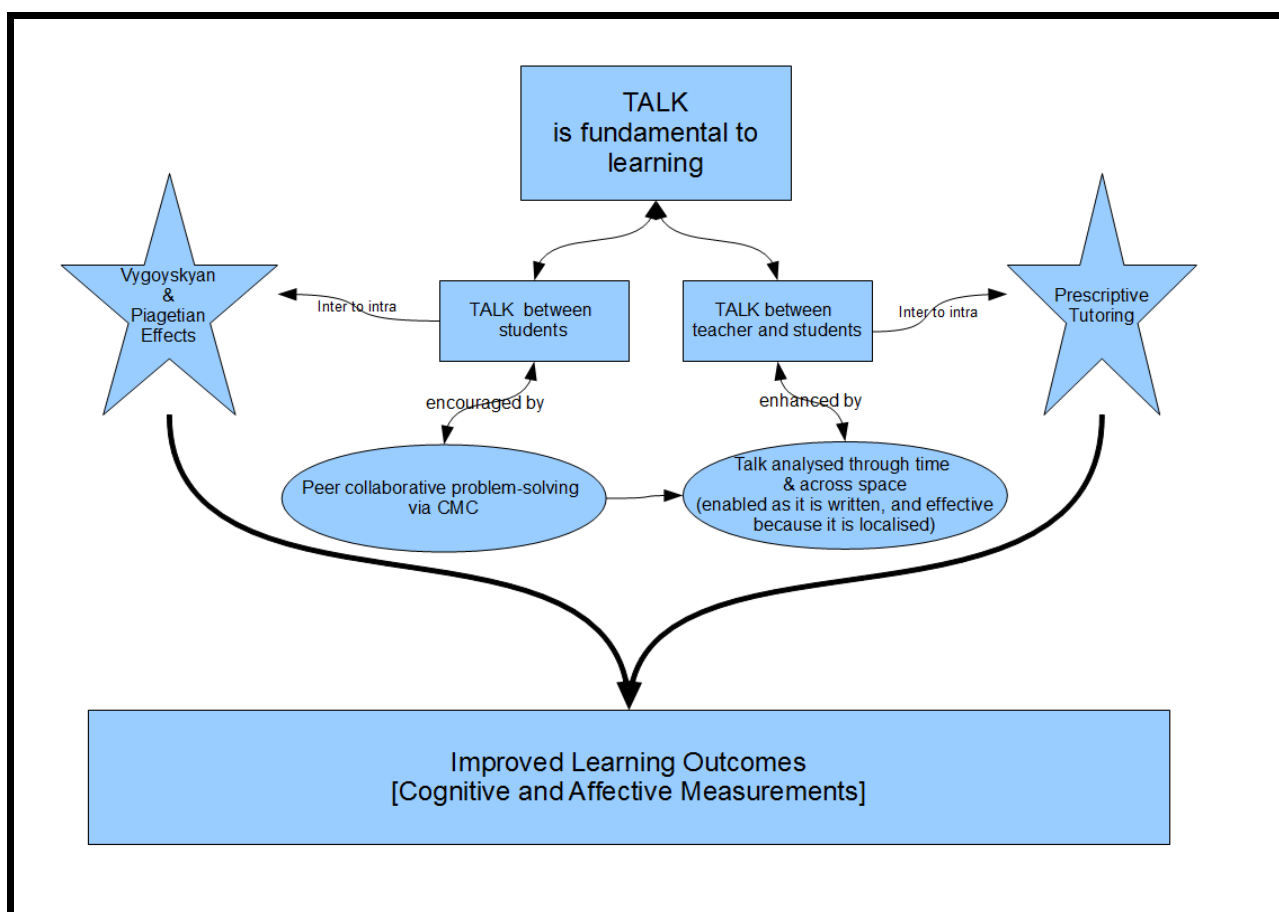


Figure 4.12: Overview of intervention design

The second part of this chapter provided a description of my research design and methodology. As my research intentions involve addressing real-world problems in the field in collaboration

with practitioners (e.g. teachers) and other relevant stakeholders (e.g. students), and integrating established theoretical foundations with experimental configurations in order to evaluate the effectiveness of the designed solutions to these problems while reflectively and iteratively evaluating the solution as well as to building new theory, design-based research is particularly relevant given the type of research study that I conducted. Chapters Five and Six will provide detailed descriptions of my research procedure and time-line, along with their respective data collection and analysis methods.

CHAPTER FIVE

PILOT STUDY DESIGN, IMPLEMENTATION & EVALUATION

This chapter focuses on the design, implementation and evaluation of the pilot study. I start the chapter by stating my research questions and describing the pre-intervention activities that were undertaken in the school. Thereafter, I provide the procedure and time-line for the pilot study. Next, I provide a discussion on my data collection and analysis, elaborating how the research questions were answered in the study. Thereafter, I provide a discussion of the findings of this pilot study, including a description of the key constructs that enabled this intervention, as well as a provision of evidence that CMCPs led to cognitive development via a Piagetian and Vygotskyan account of cognitive development.

5.1 Research Questions

The pilot study served as the first iteration of my design experiment. As per the collective agreement before access into the school was granted (see Chapter Four), the main objective of this pilot study was to determine if students who had undergone the intervention would improve in their understanding of physics concepts, resulting in improved test scores. Also, we needed to evaluate if these students were willing to continue with the intervention in 2009 for the entire academic year. Insignificant improvements or the students' reluctance to continue with the intervention would mean the end of the research study. In addition to evaluating the intervention purely from a *students' consequence* perspective, I also wanted to evaluate the intervention from a *teacher's consequence* perspective. Towards that end, I wanted to evaluate whether the protocol data gleaned from the students' problem-solving processes could provide the students' current physics teacher (Mr Ng) with additional insights into his students' knowledge base and thought processes. Hence, in short, the overarching objective of the pilot study was for me to answer the following research questions:

- (i) To what extent would I be able to obtain insights into the students' misconceptions/misunderstandings from their protocol data?

- (ii) As a result of immersion in my intervention, to what extent would students' understanding of physics concepts improve, resulting in improved test scores?
- (iii) To what extent would students be comfortable with my intervention, given their many years of exposure to other approaches?
- (iv) To what extent would the students' physics teacher find the information gleaned from the students' collaborative problem-solving processes 'insightful' and 'useful'?

5.2 Pre-Intervention Activities

I based myself in the school for about one month before the intervention started. The overarching objective of placing myself in the school earlier was for me to be assimilated into the school's culture (in order to establish rapport and trust, and have a common language when discussing students' work), as well as to lay the groundwork for my research study. At this stage (and throughout the intervention), I was provided a shared workspace in a room where the IT assistants and relief teachers occupied. This room was on the second floor of the school building and located right next to the teachers' common room, where Mr Ng was based. During this time, I got to know many people in the school (e.g. other teachers, IT technicians), and built up a working relationship with Mr Ng, the pure-physics teacher who had been teaching 4E1 since June 2008. Mr Ng was recently posted into the school, and had taken over the class from Ms Er, who had taught the students from January to May 2008. I spent some time with both Mr Ng and Ms Er in order to explain to them the details of my research study, including the intervention process, commitment required, and expected results. We also spent some time discussing about the topics to be tested during the pilot study. I also built up a working relationship with Mr Das, the school's computer laboratory technician who takes care of the computer laboratories and other IT hardware infrastructure (he reports to the Head of Department for IT). Together, we spent some time experimenting with the various settings in the computer laboratory in order to ensure that all technical issues were ironed out and also to minimise set-up time.

More importantly, I was given the opportunity to address the students in order to talk to them

about the intervention. Essentially, I explained to the students that getting a good grade in physics was a likelihood if they truly understood what they were taught, and my revision intervention helps with this process by allowing their physics teacher to 'see' how/what they were thinking when solving physics problems. Also, I suggested that it was possible that they might end up helping each other understand physics concepts better, given the fact that they could probably relate to each others' experiences better. I also handed out the Informed Voluntary Participation forms (see Appendix 5.1) which were collected back a week later, and also conducted an initial survey to ascertain the students' interest in physics, among other things (see Appendix 5.2).

5.3 Pilot Study Procedure and Time-line

The pilot study was carried out from 20 Oct to 5 Nov 2008. Out of the 23 students in 4E1 that took pure-physics, three of them had consistently failed physics, and were earmarked during the school's end-of-year promotion exercise to drop the subject the following year (the students were not informed of this decision at the time of the pilot study). It is a common practice for students in Singapore to drop a subject at the start of secondary four so that they have more time for their other subjects. Consequently, it is a common practice for teachers to recommend to students on which subject(s) they should drop out off at the start of secondary four. Out of these 23 students, 21 students (10 boys, 11 girls) were consistently present during the research study period (one student was on medical leave and the other student was on overseas leave during that period) and, hence, the pilot study focused only on these 21 students.

A pre-test and a post-test covering concepts from *Physical Quantities, Units and Measures, Kinematics, and Energy, Work, and Power* was created by me and vetted by Mr Ng prior to the intervention. It should be noted that there are many concepts covered within each topic, and only the key concepts within the topics were chosen for this pilot study. In order to ensure that the pre- and post- test were of similar standards, each post-test question was crafted as a direct adaptation of a pre-test question, therefore testing the same underlying concepts. The

questions posed were adapted (I made the questions more contextualised) from actual GCE 'O' level questions, and the concepts tested had already been taught (and examined) as part of the students' secondary three syllabus. However, I selected questions that were of a higher level of difficulty and hence expected that students would find the tests difficult.

The pre-test was given to all 21 students on 20 Oct 2008, which was one week after the students' end-of-year physics examination. This pre-test was then scored by me and, in order to ensure consistency of marking, the scoring was reviewed by a physics teacher in the school who was not involved in the intervention (Mr Lim, who has about three years of experience teaching physics at the combined-science level), who found the scoring to be consistent. Correlation analysis of the 21 students' secondary three final examination scores and their pre-test scores (see Figure 5.1) show that the students' pre-test scores are significantly ($p < 0.001$) highly correlated ($r = 0.673$) with their end-of-year examination scores. This finding indicates that the pre-test (and by extension, the post-test) would provide us with a reliable proxy for gauging students' understanding of the physics concepts covered.

Correlations				
			Sec3Finals	PreTest Scores
Spearman's rho	Sec3Finals	Correlation Coefficient	1.000	.673**
		Sig. (2-tailed)	.	.001
		N	21	21
	PreTestScores	Correlation Coefficient	.673**	1.000
		Sig. (2-tailed)	.001	.
		N	21	21

** . Correlation is significant at the 0.01 level (2-tailed).

Figure 5.1: Correlation analysis between secondary three final examination scores and pretest scores

In order to evaluate the intervention, we (Mr Ng and I, in consultation with Ms Er) split the class into three groups – an experimental group (XG) who underwent my intervention, a control group (CG) who only revised physics by themselves, and an alternate intervention group (AG) who had private tutors for physics. In order to place the students into their respective groups, we surveyed the students on whether they were interested to take part in

the pilot study and also whether they had private tuition on physics. Out of these 21 students, seven had private physics tutors and, hence, those students formed the AG. It is a common occurrence for students in Singapore to attend private tuition lessons (i.e. they are not reserved for the wealthy), hence the fact that about a third of our students had private physics tutors did not surprise us. 14 students volunteered to be part of the experimental group, out of which nine students had no private physics tutors. Hence, Mr Ng selected eight of these nine students to form the XG. The remaining six students formed the CG. However, one student in the XG attended only the first CMCPs session (she was on medical leave for the next three days) and hence, was removed from the XG and placed in the CG. Therefore, I considered that there were seven students in each group, with four boys and three girls in XG.

Out of a maximum score of 36, the mean pre-test score for CG was 14.36 (SD = 6.24), AG was 8.07 (SD = 4.24), and XG was 9.86 (SD = 4.71). Because the groups were not randomly assigned, I wanted to ensure that there was independence of the pre-test (which is the covariate in my ANCOVA) and treatment effect (the groupings). The Levene statistic for the test of homogeneity of variances was not significant ($p=0.392$), and with an F-test result for the pre-test covariate at $F(2,11.744) = 2.30$, $p = 0.143$, it indicated that the pretest and the treatment effect were indeed independent. (see Figure 5.2).

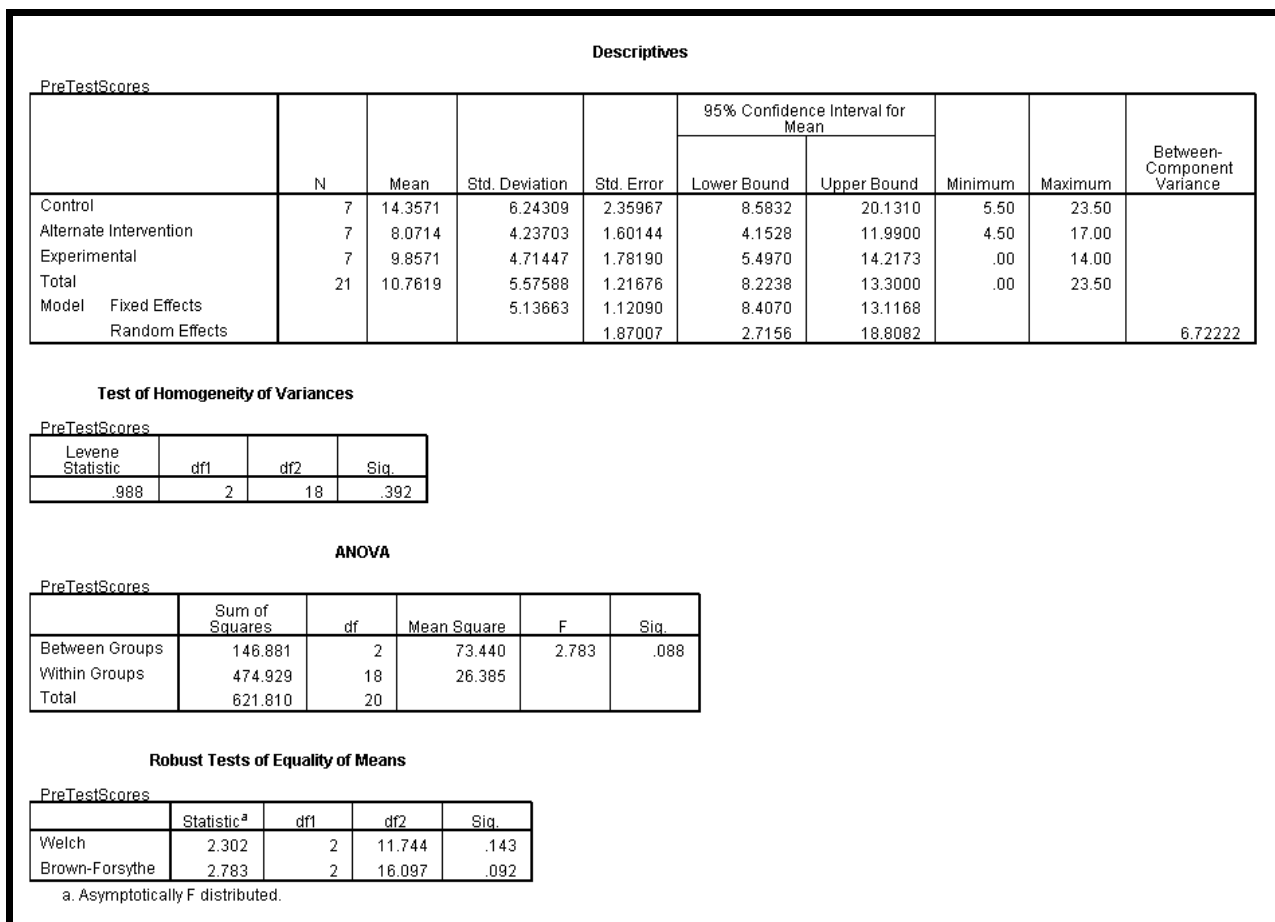


Figure 5.2: Test for homogeneity of variances (pre-test) / independence of the pre-test and treatment effect

Students in XG attended three cycles of CMCPs and PT sessions. These sessions were conducted in one of the school's newer computer laboratory after regular class hours. The intervention was solely conducted by me as Mr Ng was involved in other school activities at that time. Each cycle (a CMCPs and a PT session) covered concepts from either *Physical Quantities, Units and Measures, or Kinematics, or Energy, Work, and Power*, and the three cycles were conducted over a 2-week period (see Table 5.1). The total contact hours for XG were about 9 hours.

Table 5.1: Schedule of the main activities in the pilot study

Date	Event
13 Oct 08	- School's official end-of-year physics exam (all students) [2 hr 15 mins]
20 Oct 08	- Intervention Pretest (all students) [45 mins]
28 Oct 08	- Computer-mediated collaborative problem-solving session 1(XG) [1 hr 15 mins]
29 Oct 08	- Prescriptive tutoring session 1 (XG) [1 hr 45 mins]
30 Oct 08	- Computer-mediated collaborative problem-solving session 2 (XG) [1 hr 15 mins]
31 Oct 08	- Prescriptive tutoring session 2 (XG) [1 hr 45 mins]
3 Nov 08	- Computer-mediated collaborative problem-solving session 3 (XG) [1 hr 15 mins]
4 Nov 08	- Prescriptive tutoring session 3 (XG) [1 hr 45 mins]

5 Nov 08	<ul style="list-style-type: none"> - Intervention Post-test (all students) [45 mins] - Focus Group (XG students) [30 mins] - Interviews (XG students) [30 mins each student]
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5.4 Data Collection, Analysis, and Findings

5.4.1 Obtaining Insights into Students' Knowledge Base and Thought Processes

As a main objective of PT (see Chapter Four) is to obtain insights into students' misconceptions and misunderstandings by *reviewing* their recorded collaborative problem-solving attempts, the answer to the first research question (to what extent would I be able to obtain insights into the students' misconceptions/misunderstandings from their protocol data) could be obtained by summarising data from the PT 'notes' made during the pilot study. Since three cycles of the intervention were conducted, there were three PT 'notes' that I had made and handed out to the students during the intervention. Figure 5.3, 5.4 and 5.5 provides an example of one slide from each of the three PT sessions (Appendix 5.3 provides the questions posed for the first CMCPS session, while Appendix 5.4 provides the complete 'notes' handed out to students for its subsequent PT session). Table 5.2 provides an elaboration of what I term as a 'misconception' or 'misunderstanding', and provides readers with an idea of how the protocol data was reviewed and analysed. The snippet shown in Table 5.2 was taken verbatim from one student dyad's co-construction efforts, and it manifests the misconception/misunderstanding Mumo (all students names have been made anonymous; in this dissertation, once an anonymous name has been assigned to a particular student, that same name is used throughout the dissertation) had with regards to what 'direction' means in physics terminology. When appropriate, I provide comments in square brackets ([...]) to aid the reader in understanding the context of the students' problem solving attempts.

Question 1b: Which of the following are scalars and which are vectors? Answer

- Velocity, Speed, Distance, Displacement, Time, Temperature, Force, Mass, Acceleration

Mostly no problems:

Bibi _	1b) scalar : speed, distance time temperature mass and vector : velocity displacement force and acceleration.
Ziki _	okay

BUT...this is worth discussing:

Wewa _	if vector, needs direction right
Cece _	mean acceleration got increasing and decreasing so ,isnt it directon?
Wewa _	temperature also have increasing n decreasing

Cece _	acceleration is vector right ?
Wewa _	ya it is
Cece _	so there is no directoin in acceleration
Wewa _	but vector must hav direction
Cece _	ya
Wewa _	that means acceleration also hav direction

Figure 5.3: Misconception/misunderstanding of the meaning of 'direction' in physics terminology (from PT session 1)

Question 1a

- A remote controlled helicopter, hovering at a height of 100 metres above the ground, dropped a round rubber "bomb". You estimated the time it took for the rubber bomb to reach the ground was 4.47 seconds. What is the final velocity of the rubber bomb just before it hits the ground?

Rera _	velocity is with direction
Qeqe _	so speed is 22.37...m/s
Yayi _	speed=100/4.47
Rera _	speed 100/4.47

Velocity = Displacement/TOTAL time
 = 100m/4.47s
 = 22.37136465m/s

Abba _	rate of displacemtn / time
Abba _	displacement*
Abba _	100/4.47?
Lenni _	initial velocity is 100/4.47
Lenni _	1a) 022.4m/s..

Yayi _ 22.37 is the average speed it is not what we need

*Every group used:
 Velocity = displacement / time.
 This formula is correct, but cannot be applied to situation when acceleration is NOT ZERO! As Yayi said below, 22.37m/s is the AVERAGE SPEED, and NOT the FINAL VELOCITY*

Figure 5.4: Misconception/misunderstanding of when to apply the speed = distance / time formula (from PT session 2)

Question 2a

Two balls (A and B) of mass 1kg each were pushed up a hill as shown below. What is the work done on Ball A and Ball B by moving them from the bottom to the top of the hill?

Abba _	-160J/s
Gigi _	got per sec meh?
Momo _	ya
Gigi _	i thought joule only
Abba _	wd wat
Momo _	no
Abba _	hallo
Abba _	work done
Momo _	J/s
Abba _	not energy

*Hallo, the unit for **work done (Wd)** is the same as energy, which is Joules (J).*

J/s (or Watts) is the unit for Power!

Figure 5.5: Misconception/misunderstanding of what 'work done' means (from PT session 3)

One of the questions posed during the first CMCPs session was a typical 'recall' type question. Given a list of terms, I asked the students which of the terms referred to scalar or vector quantities. As can be seen from the discussion snippet in Table 5.2, Mumo obtained the correct answer for *acceleration* ("acceleration is vector"). In a test or examination setting, he would have obtained full marks for this test item, and deemed to have understood the concept. However, due to the dialogic nature of the CMCPs session, Dino asked him why he considered acceleration to be a vector quantity ("why?...gravity ah?"). Dino's utterance ("gravity ah?") suggests that she thinks that *gravity* is a vector quantity, but is unsure if acceleration and gravity are equivalent. Mumo responded that he had not considered *gravity* ("no"), and Dino probed further by asking, "then?". As a result, Mumo revealed an interesting insight; he felt that acceleration was a vector quantity because its magnitude could increase and decrease ("increase and decrease acceleration...right?"). Baffled by Mumo's explanation, Dino sought clarification ("huh...wat u talkin?") and stated that a vector quantity has a direction component to it ("if vector needs direction right"). As a result of the further probing from Dino, Mumo made explicit his conceptions about 'direction' by stating that, in his opinion, 'direction' constitutes increasing or decreasing magnitudes ("i mean acceleration got increasing and

decreasing so ,isnt it directon?"). Dino then pointed out that *temperature* can also increase and decrease in magnitude ("temperature also have increasing n decreasing"), and since Mumo had earlier commented (not shown in Table 5.2) that temperature is a scalar quantity ("temperature is scalar") and supposedly knew the difference between vectors and scalars (he had earlier wrote that, "i think it is vector that has magnitude and direction"), she is indirectly suggesting that his conception of what constitutes 'direction' might be wrong.

From the snippet provided in Table 5.2, I draw three important observations. Firstly (and not surprisingly), it is entirely possible that students provide correct answers to questions even though they do not understand the fundamental concepts involved. Of value to teachers is not this observation, but a practical approach that would help them recognise that such an incident has occurred, and I argue that the methods used in this intervention present one such approach. Secondly, peer discussions can lead to illuminating insights; I had never encountered a conception that supposes that 'direction' may be said to constitute an increase or decrease in magnitude. In fact, neither Mr Ng nor Ms Er had ever encountered such a conception. In our opinions, the term 'direction' is very straight-forward and we never conceived that it could be misconstrued. Thirdly, we could access how Dino and Mumo were thinking while *simultaneously* accessing how other students were thinking due to the unique affordance of ICT. The way we used ICT allowed for a new communications genre to take place, while ensuring that the discourse was recorded and made available for our review and analysis. In a typical classroom situation, a teacher would only be able to listen in to one peer discussion at any point in time. Hence, the discourse of the other groups would not be available for teachers to review and analyse.

Table 5.2: Example of a question posed and students' discourse during the first CMCPs session, and the 'direction means being able to increase or decrease in value' insight

Question Posed	Discussion Snippet
Q1b) Which of the following are scalars and which are vectors?	Mumo: acceleration is vector <i>[Mumo's answer is correct – acceleration is a vector]</i> Dino: y?

<p>Velocity, Speed, Distance, Displacement, Time, Temperature, Force, Mass, Acceleration</p>	<p><i>[Dino is uncertain if acceleration is a vector]</i></p> <p>Dino: gravity ah?</p> <p><i>[This utterance suggests that Dino thinks that gravity is a vector. However, she is unsure if acceleration and gravity are equivalent (they is, but only in a specific context)]</i></p> <p>Mumo: no</p> <p>Dino: then?</p> <p>Mumo: increase and decrease acceleration</p> <p>Mumo: right?</p> <p><i>[Here we see that Mumo obtained the correct answer by incorrect reasoning. To Mumo, direction means the ability of a magnitude to increase or decrease]</i></p> <p>Dino: huh</p> <p>Dino: wat u talkin?</p> <p>Dino: if vector needs direction right</p> <p><i>[Dino is unclear what Mumo meant, and states that a “vector needs direction”. This utterance also suggests that Dino knows that “increase and decrease” do not constitute “direction”]</i></p> <p>Mumo: i mean acceleration got increasing and decreasing so ,isnt it directon?</p> <p><i>[Here, Mumo explicitly states his conception of “direction”, revealing a misconception of what “direction” means in physics terminology]</i></p> <p>Dino: temperature also have increasing n decreasing</p> <p><i>[Here, Dino points out that temperature can also increase and decrease. Since Mumo said earlier than temperature is a scalar quantity, she is indirectly suggesting that his conception of what constitutes “direction” might be wrong]</i></p>
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On a whole, the three cycles revealed 24 unique misconceptions/misunderstandings, and each misconception/misunderstanding offered an insight into the students' thought processes and knowledge base. Due to space constraints and the fact that I have already provided a fairly detailed discussion of the 'direction means being able to increase or decrease in value' insight, I shall now only briefly discuss the insights I gained from the first two CMCPs sessions. For each insight, mostly only one discussion snippet is shown below even though it was common to observe multiple groups having similar misconceptions/misunderstandings.

In Table 5.3, it can be seen that while both Taki and Gabo correctly defined the term *vector*, they thought that a scalar only has direction (and no magnitude). When students make such 'simple' mistakes, they often give the excuse that they were "careless". Indeed, when I first showed this insight to Mr Ng, he commented that they were probably "careless". However, as evident from the discourse, both Gabo and Taki had numerous opportunities to correct themselves if they had indeed been "careless" – they had not done so, and this reveals a misconception/misunderstanding on their part (and not merely a "careless mistake").

Table 5.3: 'A scalar has direction only' insight

Question Posed	Discussion Snippet
Q1a) What is the difference between a vector and a scalar?	<p>Taki: lets start with qn 1 now</p> <p>Gabo: ok</p> <p>Taki: vector-got direction and magnitude but scalar only direction agree?</p> <p><i>[First occurrence of the "scalar only direction" definition]</i></p> <p>Gabo: ya</p> <p>Gabo: so settled ?</p> <p>Taki: ok so for qn 1 ans is vector-got direction and magnitude but scalar vector-got direction and magnitude but scalar only direction .</p> <p><i>[Second occurrence of the "scalar only direction" definition]</i></p> <p>Gabo: vector - magnitude + direction , scalar - direction</p> <p><i>[Third occurrence of the "scalar only direction" definition]</i></p> <p>Gabo: can?</p> <p>Taki: yes</p>

Table 5.4 shows that both Dino and Mumo could not remember the definition of *vectors* and *scalars*, despite the fact that this topic was included in their end-of-year examination that they took about two weeks ago. Interestingly, they remembered that "the difference [between vectors and scalars] is that one got direction and the other one dont have", but they could not remember "which one".

Table 5.4: 'A scalar has both magnitude and direction' insight

Question Posed	Discussion Snippet
Q1a) What is the difference between a vector and a scalar?	<p>Dino: scalar is sth which has magnitude n direction</p> <p>Dino: u there or not</p> <p>Dino: /</p> <p>Dino : ?</p> <p>Mumo: i think it is vector that has magnitude and direction</p> <p>Dino: o</p> <p>Dino: u sure ah?</p> <p>Mumo: i dont knpw</p> <p>Mumo: know</p> <p>Mumo: the difference is that one got direction and the other one dont have</p> <p>Dino: that one i noe</p> <p>Dino: but i don noe which one</p>

In Table 5.5, it can be seen that while both Maria and Yoyo recognised that *vectors* involves direction while *scalars* do not, they did not mention about the quantity's magnitude. This is also manifested by Ziki and Sarsi (see Table 5.6).

Table 5.5: 'A vector has direction but scalar has no direction (magnitude not mentioned)' insight

Question Posed	Discussion Snippet
Q1a) What is the difference between a vector and a scalar?	<p>Maria: hey let start doing first qn</p> <p>Yoyo: okay</p> <p>Maria: 1a</p> <p>Maria: wat do u thing</p> <p>Maria: i think vector is involve direction</p> <p>Yoyo: vector has direction</p> <p>Maria: yup</p> <p>Maria: and scalar does not have direction</p> <p>Yoyo: yup</p>

Table 5.6: 'A vector has direction but scalar has no direction (magnitude not mentioned)' insight

Question Posed	Discussion Snippet
Q1a) What is the difference between a vector and a scalar?	<p>Ziki: vector is a scalar with distance</p> <p><i>[Ziki's utterance indicates that his thinks that "a vector has both magnitude + direction, while a scalar has direction only"; see also Table 5.3]</i></p>

	Sarsi: so...? u start first?
	Ziki: watever
	Sarsi: scalar is without direction Vector is with direction
	Ziki: ya

Viewed in totality, all the eight students (there were initially eight students in XG, but one student dropped out of XG after this first CMCPS session as she was on medical leave for the next three days) were not even sure of the definition of *vectors* and *scalars*, despite the fact that these are considered as foundational terms. In addition, their definitions were mostly non-identical (out of eight students, there were three different definitions) even though they had all attended the same physics lessons, learnt from the same physics teacher, and read from the same textbook. Initially, I had classified these three insights ('a scalar has direction only', 'a scalar has both magnitude and direction', and 'a vector has direction but scalar has no direction (magnitude not mentioned)') as students' misconceptions and/or misunderstandings. However, but upon further analysis, I felt that the 'misconception/misunderstanding' label might not be entirely appropriate. After all, the discourse suggests a *lack of knowledge* rather than a *misconception or misunderstanding*. While I acknowledge that misconceptions and/or misunderstandings may arise from a lack of knowledge (Fisher, 1985), getting students to correctly recall a definition does not constitute as conceptual change and, hence, a misconception/misunderstanding label would be inappropriate. Therefore, I have tentatively labelled these insights as insights into the students' 'knowledge gaps'. Further discussions on the implications of whether students have 'misconceptions/misunderstandings' or 'gaps in their knowledge' is provided in Chapter Six (section 6.5.2).

Table 5.7 shows that while Taki and Gabo knew the definition of a vector and scalar (they had eventually obtained the correct answer to the question "what is the difference between a vector and a scalar") and had correctly concluded that *speed* is a *scalar* quantity while *velocity* is a *vector* quantity, they lacked conceptual understanding of these terms, as Taki assumed

that *speed* and *velocity* were interchangeable terms.

Table 5.7: 'Speed and velocity are interchangeable terms' insight

Question Posed	Discussion Snippet
<p>Q2) An old man, starting his walk from Point O, took 1 minute to travel 3 metres North. From there, he took another 4 minutes to travel 4 metres East. Draw and label a diagram of his walk and then calculate his speed and velocity.</p>	<p>Gabo: what is the formula for velocity?</p> <p>Taki: $speed = (4+3)m / (5 \times 60)s = 0.0233m/s$</p> <p><i>[Taki obtained the correct answer for speed, which is total distance / total time]</i></p> <p>Taki: ???</p> <p>Taki: i dont think velocity got formulas</p> <p><i>[I am not sure if Taki meant that velocity has no formulas, or whether she thinks that there are no appropriate formulas for velocity in this instance. In any case, this utterance itself reveals a lack of understanding on her part]</i></p> <p>Taki: *formula</p> <p><i>[Students use the asterisk sign "*" to signify a correction to a typo made in their previous statement]</i></p> <p>Gabo: then how to caculate?</p> <p>Taki: hmm...mayb same as speed</p> <p><i>[Here, we see that to Taki, speed and velocity are interchangeable terms]</i></p>

Table 5.8 provides a continuation of Taki and Gabo's discourse as provided in Table 5.7. From their discourse, it can be seen that Taki and Gabo assumed that *distance* and *displacement* were interchangeable terms. In fact, *the discourse shows the reason why Taki felt that speed and velocity were interchangeable* – it was because, to both Taki and Gabo, *displacement and distance were interchangeable*. Their discourse suggests that Taki and Gabo did not understand the conceptual difference between *displacement* and *distance*.

From the analysis of the snippets provided in Table 5.7 and 5.8, I draw two important observations. Firstly (and not surprisingly), misconceptions/misunderstandings have a 'knock-on' effect – a lack of understanding in one area leads to further misunderstanding in other areas. In this case, a lack of understanding of the difference between *displacement* and

distance resulted in a lack of understanding between the terms *velocity* and *speed*. I further posit that it is this lack in understanding between *velocity* and *speed* that resulted in their lack of understanding between *vectors* and *scalars*, and the students' protocol data provides evidence in support of this claim. Secondly, in addition to revealing insights into students' thought processes and knowledge base (e.g. students thinking that *speed* and *velocity* are interchangeable terms), analysis of peer discussions allow teachers to see how students' conceptions are *inter-connected*. Said differently, analysis of the discussion logs of students' collaborative problem solving attempts can provide both *discrete insights* and *relational insights*. A *discrete insight* may be thought of as a *specific student misconception/misunderstanding*, such as "velocity and speed are interchangeable terms", while a *relational insight* may be thought of as the *inter-connectedness between discrete insights*, such as the conception that "displacement and distance are interchangeable terms" leading to the conception that "velocity and speed are interchangeable terms", which leads to a lack of appreciation between *vector* and *scalar* quantities. Such relational insights are difficult to obtain in a typical classroom setting due to various constraints that limits the amount of time students may engage in deep discussion about a particular physics concept or problem.

Table 5.8: 'Distance and displacement are interchangeable terms' insight

Question Posed	Discussion Snippet
Q2) An old man, starting his walk from Point O, took 1 minute to travel 3 metres North. From there, he took another 4 minutes to travel 4 metres East. Draw and label a diagram of his walk and then calculate his speed and velocity.	Taki: velocity is displacement /time Gabo: m Gabo: ok <i>[Gabo agrees that a formula for velocity is displacement / time]</i> Taki : finally rmb <i>[Taki finally remembers (rmb) the formula for velocity, which is displacement / time]</i> Gabo : so same as speed? <i>[This utterance suggests that, to Gabo, displacement and distance are interchangeable terms]</i> Gabo: i don think so leh Gabo: not sure <i>[Gabo does not think that the answer for both speed and velocity would be the same]</i>

	<p>Taki: mayb need direction??</p> <p><i>[Taki recalls that vectors have direction and, hence, suggest that perhaps direction is needed]</i></p> <p>Gabo: um</p> <p>Gabo: i don think can calculate direction</p> <p><i>[This utterance suggests a weak understanding of 'direction'; see also Table 5.2]</i></p> <p>Taki: so is the same</p> <p>Taki: ??</p> <p>Gabo: try</p> <p>Taki: so velocity=displacement /time=7m/300s=0.0233m/s</p> <p>Gabo: ok</p> <p><i>[Taki and Gabo assume that displacement and distance are interchangeable terms, and used the value for distance in place of the displacement]</i></p>
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Table 5.9 shows that Sarsi had thought that the SI units (i.e. International System of Units) for distance and displacement were both kilometres ("KM"), which was surprising because he had scored 69 (out of 100) for his end-of-year physics examination, which is almost a distinction grade (scoring 70 and above would result in a distinction grade).

Table 5.9: 'KM (kilometres) is the SI unit for distance' insight

Question Posed	Discussion Snippet
Q2) An old man, starting his walk from Point O, took 1 minute to travel 3 metres North. From there, he took another 4 minutes to travel 4 metres East. Draw and label a diagram of his walk and then calculate his speed and velocity	<p>Sarsi: SI units.</p> <p>Sarsi: -.-</p> <p>Sarsi: zzzzzzzzzzz</p> <p><i>[Sarsi and Ziki were calculating the answer for the question posed, and Sarsi said that they needed to change their answers to be in SI units]</i></p> <p>Ziki: ha</p> <p>Sarsi: u go the conversation?</p> <p><i>[Sarsi was probably asking Ziki if he overheard the conversation between me and another student]</i></p> <p>Ziki: so????</p>

	<p>Ziki: huh??</p> <p><i>[Ziki was unable what Sarsi was asking, probably due to the Sarsi's typo]</i></p> <p>Sarsi: mins change to s</p> <p><i>[Sarsi is saying that to get SI units, minutes need to be changed into seconds]</i></p> <p>Ziki: ok....</p> <p>Sarsi: m change to KM</p> <p><i>[Here, we see that Sarsi thought that the SI units for distance was "KM" (kilometres)]</i></p>
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Table 5.10 offers two interesting discrete insights. Sarsi had thought that *time* can have a negative value, since "its deceleration, so negative value is expected". I was very surprised that Sarsi could have such conceptions (i.e. I gained a discrete insight – to Sarsi, 'time can be negative'), and the fact that he related negative time with deceleration (i.e. I gained a relational insight – time could be negative because "its deceleration, so negative value is expected") was particularly insightful to us (Mr Ng, Ms Er, and myself). Ziki challenged Sarsi on his conception that time could be negative ("hallo...sth [something] is wrong...negative time?"). When Sarsi rebutted that "its deceleration, so negative value is expected", Ziki indicated that he agreed on a negative value ("ya"), but refocused Sarsi's attention on time ("sry [sorry]...time la [I'm asking about time]"). Sarsi's clarification that "acceleration when negative = deceleration so dun be so shock" indicated that (i) he still thought that time can have a negative value, since the airplane is decelerating, and (ii) he believed that negative acceleration necessarily implies deceleration (the second discrete insight gained), which is incorrect since acceleration is a vector quantity and a negative value for acceleration could well mean that an object is accelerating in the opposite direction. Of course, Sarsi did not explicitly state that he believed that negative acceleration necessarily implies deceleration; it was the analysis of the entire protocol data led me to this conclusion.

Table 5.10: "Time can be negative" and "negative acceleration necessarily implies deceleration" insight

Question Posed	Discussion Snippet
Q3a) A small airplane was trying to take off a runway when the pilot saw an object	<p>Sarsi: see how long did it brake</p> <p>Sarsi: -50</p>

<p>some distance from the runway, and decided to step on the brakes. The airplane had a total mass of 2000kg and was travelling at a speed of 150km/hr. If the object was 300 metres away from the airplane when the pilot saw it, and the maximum braking force of the airplane is 6000N, could the airplane stop in time?</p>	<p><i>[Sarsi had calculated that it took -50s for the airplane to stop]</i></p> <p>Ziki: hallo</p> <p>Ziki: sth is wrong</p> <p>Ziki: negative time?</p> <p><i>[Ziki observed that something was wrong with Sarsi's answer, since the value for time was negative]</i></p> <p>Sarsi: its deceleration, so negative value is expected</p> <p><i>[Sarsi's responded that since the airplane was decelerating, a negative value was to be expected]</i></p> <p>Ziki: ya</p> <p>Ziki: sry</p> <p>Ziki: time la</p> <p><i>[Ziki agreed on a "negative value"; even though he was not explicit on which value he was referring to]</i></p> <p>Sarsi: acceleration when negative = deceleration so dun be so shock..</p> <p><i>[This utterance provides an indication that Sarsi believes that negative acceleration necessarily implies deceleration, which is incorrect]</i></p> <p>Sarsi: time?</p> <p>Ziki: time wat</p> <p>Sarsi: 50 s lo</p> <p><i>[I believe that it is due to Ziki's continued questioning on time that Sarsi dropped the "minus" sign in front of 50s, when he stated that the time is 50 seconds...]</i></p> <p>Ziki : how u get?</p> <p>Sarsi: wait.. can we just get rid of the munus sign?</p> <p><i>[...and asks if he can just get rid of the minus sign (from -50s to 50s)]</i></p>
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Table 5.11 offers yet another interesting insight. Sarsi's utterance of "NEWTON [force] WHERE GOT NEGATIVE" indicates that he does not understand the implication of a vector quantity (Sarsi had early answered correctly that *force* is a *vector* quantity). Also, notice that when Ziki

mentioned that I had said that direction can cause a value to be negative, Sarsi simply agreed (“hmm...[o]kay...jus[t] proceed”) despite the fact that Ziki's message was not clearly articulated. Here, we see that:

Just as, if left to himself...the child who is submissive to the word of his parents [or an adult] believes without question everything he is told, instead of perceiving the element of uncertainty and search in adult thought. The self's good pleasure is simply replaced by the good pleasure of a supreme authority. There is progress here, no doubt, since such a transference accustoms the mind to look for a common truth, but this progress is big with danger if the supreme authority be not in its turn criticized in the name of reason. (Piaget, 1932, p. 409)

It is my opinion that students' misconceptions and misunderstanding stay buried within themselves due to the prevalent sociocultural practice in science classrooms that privileges teachers' instructions over students' voices. As can be seen, Ziki's mere mention that “[tea]cher...say d[i]rection have negative” was enough to stop Sarsi from further discussion about his claims that force cannot have a negative value.

Table 5.11: “A force cannot have a negative value” insight

Question Posed	Discussion Snippet
<p>Q3a) A small airplane was trying to take off a runway when the pilot saw an object some distance from the runway, and decided to step on the brakes. The airplane had a total mass of 2000kg and was travelling at a speed of 150km/hr. If the object was 300 metres away from the airplane when the pilot saw it, and the maximum braking force of the airplane is 6000N, could the airplane stop in time?</p>	<p>Ziki: braking force is deceleration</p> <p>Sarsi: assume that time for braking is 50</p> <p><i>[Due to repeated queries from Ziki, Sarsi simply got rid of the minus sign and assumed that it was 50s]</i></p> <p>Ziki: so is -6000N</p> <p><i>[Ziki had calculated that the force of the airplane was -6000N]</i></p> <p>Sarsi: NEWTON WHERE GOT NEGATIVE?</p> <p><i>[This utterance indicates that Sarsi does not understand the implication of a quantity being a vector; a negative value would be that the airplane was experiencing a force in the opposite direction of its motion]</i></p>

	<p>Sarsi: a = 3</p> <p>Sarsi no negative</p> <p>Ziki: cher</p> <p><i>[Ziki is trying to explain to Sarsi that I (cher is meant to represent the word 'teacher')...]</i></p> <p>Sarsi: but because its its decelerating..... thats why i put negative at my 2nd working</p> <p>Ziki: say dorection have negative</p> <p><i>[...said that direction can cause a value to be negative, even though the message was not clearly articulated]</i></p> <p>Sarsi: hmm,</p> <p>Sarsi: kay l</p> <p>Sarsi: jus proceed</p> <p><i>[Here, we see that Sarsi did not challenge Ziki, presumably because I had said that a negative value for 'force' was possible]</i></p>
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In Table 5.12, it can be seen that Mumo (and by extension, Dino) did not know that finding a resultant force on an object requires vector addition. What Mumo had done was essentially adding two perpendicular vectors as if there were acting in the same direction. Once again, I believe this is due to a lack of understanding of vector quantities, bearing in mind that Mumo's conception of 'direction' is the ability of a quantity's magnitude (e.g. Force) to increase or decrease (see Table 5.2).

Table 5.12: 'Finding resultant force does not require vector addition' insight

Question Posed	Discussion Snippet
<p>Q3a) A small airplane was trying to take off a runway when the pilot saw an object some distance from the runway, and decided to step on the brakes. The airplane had a total mass of 2000kg and was travelling at a speed of 150km/hr. If the object was 300 metres away from the airplane when the pilot saw it, and the maximum braking force of the airplane is</p>	<p>Mumo: $F-f=ma$</p> <p>Dino: use that ?</p> <p><i>[The students have learnt in class that in order to find the resultant 'force', one formula applicable was $F-f = ma$, where F is the force on the object, and f is the frictional force the object experiences]</i></p> <p>Mumo: $2000(10)-6000=ma$</p> <p><i>[Mumo calculated that the force on the airplane was $2000 \text{ kg} \times 10 \text{ m/s}^2$, while the frictional force was assumed to be 6000N. However, he failed to</i></p>

6000N, could the airplane stop in time?	<p>recognise that the force on the airplane that he calculated was its weight (downwards), while the frictional force was acting sideways. Hence, this reveals that he did not recognise the implications of vectors]</p> <p>Mumo: $14000=ma$</p> <p>Dino: mass is 2000</p> <p>Mumo: $14000=2000(a)$</p> <p>Dino: then find acceleration?</p> <p>Mumo: $a=7$</p>
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Tables 5.13 and 5.14 show Dino's, Gabo's and Maria's confusion over initial and final velocities. In their opinions, the round rubber bomb would eventually come to rest on the ground and, hence, as a result, believed that the *final velocity* should be 0 m/s. However, since the question had asked them to calculate the bomb's velocity, they assumed that the question was asking for *initial velocity*, even though the question had stated that they were to find "the final velocity of the rubber bomb just before it hits the ground". In other words, to the students, the *final velocity* asked in the question was the equivalent of the *initial velocity* which they were trying to calculate. In my opinion, those students could have been confused between initial velocity and final velocity because they had misinterpreted the question. They assumed that since the bomb was to hit the floor, its *final velocity* would therefore necessarily be 0 m/s. However, since the question required them to calculate a value for the bomb's velocity, they assumed it was *initial velocity* that they had to find. It is interesting that all three students did not stop to consider that it was implausible that the initial velocity of the bomb was not 0 m/s, since the question had stated that it was "hovering at a height of 100 metres above the ground". Additionally, Maria (and all of the students) had tried to obtain the answer for the bomb's velocity via the formula $velocity = displacement / time$, when the application of this formula is inappropriate in the given context as acceleration is not zero (since acceleration due to gravity was in play).

Table 5.13: 'Confusion between initial velocity and final velocity' insight

Question Posed	Discussion Snippet
Q1a) A remote controlled helicopter, hovering at a height of 100 metres above the ground, dropped a round rubber "bomb". You estimated the time it took for the rubber bomb to reach the ground was 4.47 seconds. What is the final velocity of the rubber bomb just before it hits the ground?	<p>Dino: i thought final shld be 0</p> <p><i>[Dino is saying that, in his opinion, the final velocity of the bomb should be 0 m/s]</i></p> <p>Sarsi: hmm...</p> <p>Sarsi: when the bal is released from the helioper</p> <p><i>[Sarsi is drawing attention to the moment when the bomb was released]</i></p> <p>Dino: then initial is the inknown</p> <p>Dino: _unknown</p> <p><i>[Dino is actually suggesting that the final velocity is 0 m/s, while the question was asking them to work out the initial velocity]</i></p>

Table 5.14: 'Confusion between initial velocity and final velocity' and 'velocity = displacement / time can be used to calculate displacement in all situations (even when the object is accelerating or decelerating)' insights

Question Posed	Discussion Snippet
Q1a) A remote controlled helicopter, hovering at a height of 100 metres above the ground, dropped a round rubber "bomb". You estimated the time it took for the rubber bomb to reach the ground was 4.47 seconds. What is the final velocity of the rubber bomb just before it hits the ground?	<p>Maria: hey they asking for the rubber round</p> <p>Maria: bomb*</p> <p>Maria: to reach the ground</p> <p>Maria: final velocity</p> <p>Maria: is the ground rite</p> <p>Gabo: ya</p> <p><i>[Here, we see that both Maria and Gabo are focused on "the ground", rather than "just before it hits the ground"]</i></p> <p>Maria: so i think is 0 m/s</p> <p>Gabo: final is 0</p> <p><i>[Probably because of their focus on the bomb being on "the ground", they concluded that the final velocity must be 0 m/s]</i></p> <p>Gabo: initial is?</p> <p>Maria: initial is from the top..</p> <p><i>[Gabo and Maria knows that initial velocity is the velocity of the bomb "from the top".]</i></p>

	<p>Maria: then</p> <p>Maria: ?</p> <p>Gabo: um</p> <p>Maria: but they ask for final</p> <p>Gabo: rate of displacement / time</p> <p>Gabo: displacement*</p> <p>Gabo: 100/4.47?</p> <p><i>[Here, we see Gabo applying the formula Velocity = Displacement / Time. However, this is an incorrect application of the formula, since acceleration in this case is not zero]</i></p> <p>Maria: initial velocity is 100/4.47</p> <p>Maria: m/s</p> <p><i>[Despite knowing that the initial velocity is "from the top", Maria did not consider that it should be 0 m/s]</i></p>
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Figure 5.6 shows Maria's and Gabo's whiteboard drawing (which were similar to other groups), depicting their conception of the velocity-time (VT) graph of the bomb. They had drawn the VT-graph in order to obtain the *initial velocity* of the bomb (see Table 5.15). While their numerical answer was correct (the final velocity just before the bomb hits the ground was 44.7 m/s), their graph and 'labels' were incorrect. They had depicted (consciously or otherwise) their VT-graph such that it looked similar to the motion of the bomb! Importantly, they had failed to consider the implication of the graph they had drawn – if the bomb had indeed travelled as per their depiction, it would actually start off fast and slowed down until it reached the ground, where it comes to rest (0 m/s). In my opinion, the reason that the students were perfectly happy with their solution was because they had not considered the implication and plausibility of their depiction.

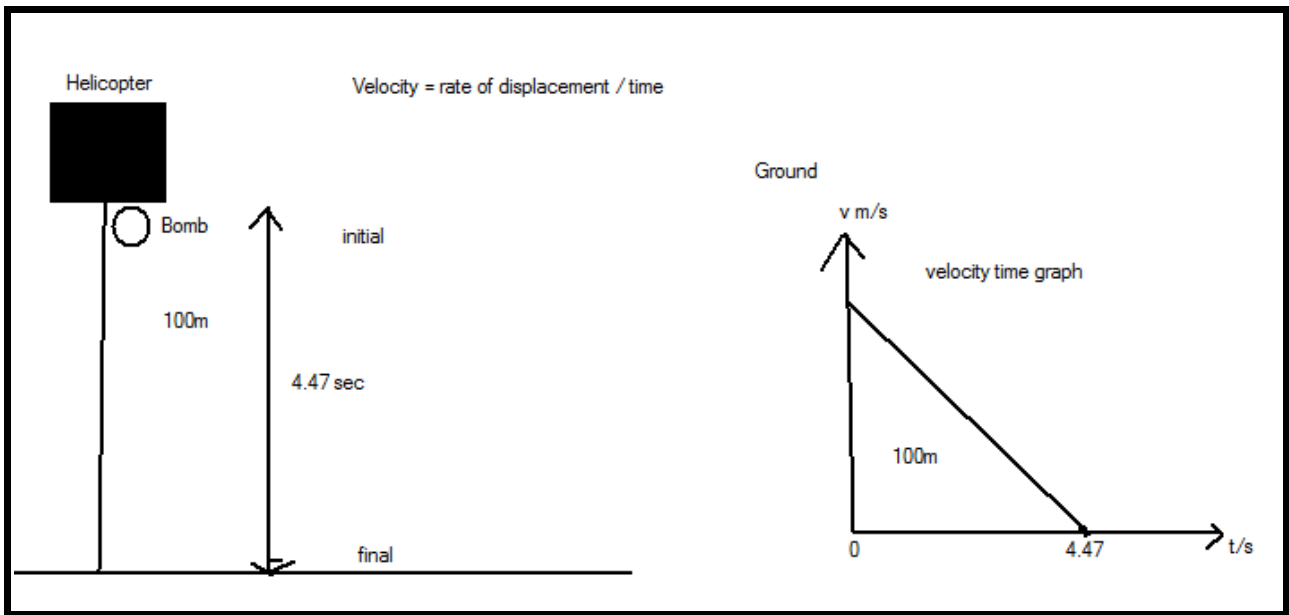


Figure 5.6 'The VT graph of a falling object mirrors its motion' insight

Table 5.15: 'The VT graph of a falling object mirrors its motion' insight

Question Posed	Discussion Snippet
Q1a) A remote controlled helicopter, hovering at a height of 100 metres above the ground, dropped a round rubber "bomb". You estimated the time it took for the rubber bomb to reach the ground was 4.47 seconds. What is the final velocity of the rubber bomb just before it hits the ground?	<p>Gabo: look at velocity time graph again</p> <p>[Gabo is referring to the graph depicted in Figure 5.6]</p> <p>Maria: just before it hit the ground...</p> <p>Gabo: 0m/s?</p> <p>Maria: no..</p> <p>Maria: $100 = 1/2 \text{ time } 4.47 \text{ time height}$</p> <p>Maria: so is 44.7m/s</p> <p>[Here, Maria calculated the value for the bomb's initial velocity by using the "area of triangle" formula. Area of triangle = $\frac{1}{2} * \text{base} * \text{height}$, therefore $100 = \frac{1}{2} * 4.47 * \text{height}$, which gives a height (velocity) value of 44.7m/s]</p>

Table 5.16 shows a continuation of Gabo and Maria's problem-solving attempts some time after they thought they had successfully solved Q1a (see Table 5.15). The fact that both Gabo and Maria used 44.7 m/s as the *final velocity* and 0 m/s as the *initial velocity* indicates either confusion or desperation on their part. In addition, the fact that both Gabo and Maria had used 4.47s as the value for *time* indicates confusion on the appropriate time to use, or pure desperation to randomly put in any number in order to get an answer. The protocol data

shows clearly that while Gabo and Maria have knowledge about the formulas to be used, they lack conceptual understanding on how to use the formulas. Students commonly complain that they know facts and formulas, but are unable to apply them correctly. Here, we see the reason – often, students lack conceptual understanding on the concepts embedded within the formula. Hence, to help students improve, what is needed is not to get students to 'solve more problems' but rather, help students build conceptual understanding.

Table 5.16: 'Confusion between initial velocity and final velocity' and 'confusion on appropriate time to use' insights

Question Posed	Discussion Snippet
<p>Q1b) Upon hitting the ground, the round rubber bomb bounced back directly upwards with a velocity of 72km/hr. You estimated that the bomb spent 0.1 seconds on the ground before bouncing back upwards. If the bomb has a mass of 100g, what is the force the ground exerted on the round rubber bomb?</p>	<p>Gabo : final is 44.7</p> <p>Gabo : -_-"</p> <p>Gabo : m/s</p> <p><i>[In order to calculate the bomb's acceleration, Gabo needed to find the bomb's final velocity and initial velocity after it hit the ground and bounced back up. Because their earlier attempts were unsuccessful, Gabo felt that the final velocity to be used now would be the initial velocity that they had previously calculated]</i></p> <p>Gabo : so</p> <p>Gabo : $acc=44.7-0 / 4.47$</p> <p><i>[Gabo felt that the initial velocity for this question would be 0 m/s, since the bomb had no velocity when it was on the ground. In addition, they had used the time that was previously given (4.47s) instead of the 0.1s given in this part of the question]</i></p> <p>Maria : $44.7-0/4.47$</p> <p><i>[Maria's workings mirror that of Gabo's]</i></p> <p>Gabo : $f=0.1$ multiply by 0.1</p> <p>Gabo : 0.1multiply by 10</p> <p>Gabo : *</p> <p><i>[The asterisk "*" is used to indicate that a typo had occurred in an earlier sentence. In this case, Gabo is saying that "0.1 multiply by 10" supersedes "f=-0.1 multiply by 0.1"]</i></p> <p>Gabo : so</p> <p>Gabo : it is 1N</p> <p>Maria : 1N</p>

Table 5.17 provides a continuation of Gabo and Maria's problem-solving attempts some time after they were told that their answer (to Q1b) was incorrect. Maria had concluded that the correct values for the *final velocity*, *initial velocity*, and *time* should be *20m/s*, *44.7 m/s*, and *0.1s* respectively. However, she (and Gabo) neglected to include a negative (-) sign for final velocity, since the bomb was travelling in the opposite direction when it "bounced back directly upwards". This mistake is attributable to a (still) weak understanding of the implication of vector quantities. I had, on the previous day, spent some time talking to the students about vectors and scalars quantities, focussing specifically on what 'direction' meant in physics terminology. I had indirectly discussed about the implication of an object's direction on the magnitude of its average velocity (see Figure 5.7). The protocol data, however, indicated to me that more needed to be done to address this lack of understanding.

Table 5.17: 'There is no need to include a negative sign (-) for an object's velocity when it moves in the opposite direction' insight

Question Posed	Discussion Snippet
Q1b) Upon hitting the ground, the round rubber bomb bounced back directly upwards with a velocity of 72km/hr. You estimated that the bomb spent 0.1 seconds on the ground before bouncing back upwards. If the bomb has a mass of 100g, what is the force the ground exerted on the round rubber bomb?	Maria: spent 0.1s <i>[Maria is echoing the text of the question, which stated that the "bomb spent 0.1 seconds on the ground"]</i> Maria: they ask for ground <i>[Maria is trying to analyse which value for 'time' is appropriate for use in the formula]</i> Gabo: 44.7m/s is the initial Gabo: 20 is the final <i>[Gabo finalises that the initial velocity is 44.7 m/s, and the final velocity is 20 m/s. Notice that despite the opposite direction, he did not put a negative sign in front of the final velocity]</i> Gabo: then the time Gabo: is Gabo: ? Gabo: 4.47? <i>[Gabo is still unclear on the time to be used in the formula]</i> Maria: i got it

Maria: $44.7 - 20 = 24.7 \text{ m/s}$
[Maria is trying to use the formula "acceleration = $v - u / t$ ". Notice that she has used the wrong values, and despite the opposite direction, did not put a negative sign in front of the final velocity]

Gabo: 44 is initial
 Gabo: 0.0
 Maria: $24.7 / \text{time which is } 0.1$
 Maria: sorry
[Maria is apologising for using the wrong values]

Maria: 44.7 is initial the 20 is final
 Maria: time 0.1
[Maria clarifies on the initial and final velocity to be used, and stated that the time to be used should be 0.1s]

Maria: acceleration
 Gabo: so
 Gabo: $20 - 44.7$
 Maria: force = 24.7 n
 Gabo: 24.7 N
[Both Maria and Gabo obtained this answer by the formula, acceleration = $v - u / t$, therefore acceleration = $20 - 44.7 / 0.1 = 24.7 \text{ N}$. However, because they had neglected to include a negative (-) sign in front of the final velocity's value, they obtained an incorrect answer]

Question 2 Answer

■ An old man, starting his walk from Point O, took 1 minute to travel 3 metres North. From there, he took another 4 minutes to travel 4 metres East. Draw and label a diagram of his walk and then calculate his speed and velocity.

by pythagoras theorem
distance of the black line = root of (9+ 16)
= root of 25
= 5m

Therefore Velocity = Total Displacement
Total time

= 5m / 5 min
= 5m / 300s
= 1/60
= 0.01666666666666667
= 0.0167 m/s (3 S.F)

No one stated the DIRECTION of the velocity!

From O to A

Figure 5.7: Discussion of implication of an object's direction on its average velocity

Table 5.18 provides a manifestation of what Soong and Chee (2000) termed as the “stepwise velocity increment conception” (p. 171). To Sarsi, when an object accelerates at 10 m/s^2 , the distance it covers increases by 10m every second because its velocity increases by 10 m/s every second (Sarsi had explain this conception to me when he and Dino could not come to an agreement). To Sarsi, if an object accelerates at 10 m/s^2 starting from 0 m/s, then in the 1st second, it's velocity would be 10 m/s, and in the 2nd second, it's velocity would be 20 m/s. Hence, he reasoned that the distance travelled in the 1st second would be 10m, and in the 2nd second would be 20m (see Figure 5.8). Of course, objects' velocities do not increase instantaneously and, hence, Sarsi's conception was incorrect.

Table 5.18: 'Objects accelerate in a 'step-wise' manner' insight

Question Posed	Discussion Snippet
Q2a) A bird was flying	Sarsi : according to the units
100 metres from the	Sarsi : m/s^2
ground when it excreted a	Sarsi : 10 m/s^2
dropping. Draw a	Sarsi : right?
velocity-time graph and	[Sarsi is attempting 'unit analysis' on the concept of acceleration]
find out how long it took	

<p>for the dropping to hit the ground.</p>	<p>Dino : ya</p> <p>Sarsi : means</p> <p>Sarsi : 1 sec can travel 10 m</p> <p>Sarsi : right?</p> <p><i>[Here, Sarsi makes a mistake; "1 sec can travel 10 m" is what happens if an object travels at 10m/s, not if it accelerates at 10 m/s²]]</i></p> <p>Dino : o!</p> <p>Dino : like yesterday</p> <p><i>[In the previous day, I had talked about how 'unit analysis' may help in deriving at the answer to a question]</i></p> <p>Sarsi : so 2 s can travel 20?</p> <p>Sarsi : right?</p> <p><i>[This is incorrect;</i></p> <p>Dino : yes</p> <p><i>[Dino is saying yes to Sarsi's comment that "1 sec can travel 10m...so 2 s can travel 20", which is technically correct]</i></p> <p>Sarsi : in total</p> <p>Sarsi : now many metres traveled in 2 sec?</p> <p>Dino : then 100/10 ah?</p> <p>Sarsi : u ans my question first..</p> <p>Dino : 20m</p> <p><i>[Dino's answer is actually correct! If an object starts from rest and accelerates at 10m/s² for 2 seconds, then it would have travelled a total of 20 metres in that 2 seconds]</i></p> <p>Sarsi : WRONG</p> <p><i>[Because of Sarsi's conception, he thinks that Dino is "WRONG"]</i></p> <p>Dino : huh</p> <p>Dino : y?</p> <p>Sarsi : FIRST sec 10 m SECOND sec 30 m</p> <p><i>[Here, we see evidence of Sarsi's "stepwise velocity increment" concept]</i></p> <p>Dino : y?</p> <p>Sarsi : it will increase by 10 in every sec.</p>
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	Sarsi : ACCELERATION
	Sarsi : the 2nd sec it will travel 20 m right?
	Sarsi : so AFTER 2nd sec, total dis traveled = 20 + 10 = 30m
	[Sarsi is essentially saying that velocity increases in a step-wise manner. See Figure 5.8]

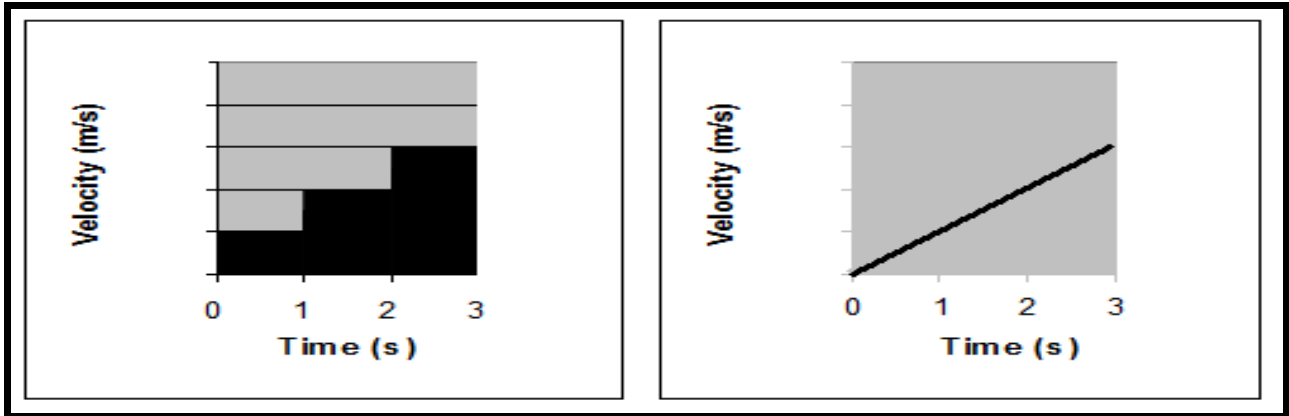


Figure 5.8: Sarsi's conception of acceleration and how the velocity of an object increases (depicted on the left), vs the correct model (depicted on the right)

Table 5.19 shows that Maria and Gabo used the principal of conservation of energy ($GPE = KE$) literally regardless of the situation. Maria and Gabo had calculated that the gravitational potential energy of the dropping was 0.25J, and it was implied in their discussion that they assumed that the value for the kinetic energy would be the same "Gabo: so 0.25J then? Maria: so ans 0.25N"). I had initially thought that this could be a careless mistake, but when I reviewed the logs with the students during subsequent PT session, it was confirmed that the students' conception of 'KE=PE' was present. Also, I noted from the logs that Maria had a poor understanding of the difference between Newtons (a *force* quantity) and Joules (an *energy* quantity). The need for me to use the PT session in order to get confirmation on the students' conceptions reaffirms my belief that the CMCPs and PT sessions necessarily go hand-in-hand; the CMCPs session provides teachers with insights to how students are thinking (or might be thinking), and the PT session provides confirmation and clarification.

Table 5.19: 'KE = PE is taken literally regardless of situation; KE's value will always equal PE's value' insight

Question Posed	Discussion Snippet
Q2b) If the dropping had	Maria : gravitatioonal potential energy
a mass of 1g, what was	Gabo : mgh

<p>its kinetic energy when it was 25 metres from the ground?</p>	<p><i>[The students have learnt that gravitational potential energy can be calculated by the formula $GPE = mgh$]</i></p> <p>Gabo : 0.001 multiply 10 multiply 25</p> <p>Gabo : 0.25</p> <p>Maria : (0.1)(10)925)</p> <p>Gabo : correct?</p> <p>Gabo : 0.25 J</p> <p>Maria : yyaya</p> <p>Maria : 0.01 kg</p> <p>Gabo : 0.001</p> <p>Maria : i forgot to convert</p> <p>Gabo : 0.001kg</p> <p>Gabo : 1g mah</p> <p>Maria : sorry 0.001kg</p> <p>Maria : hahha</p> <p>Gabo : k</p> <p>Gabo : so 0.25J then?</p> <p><i>[Gabo had found the answer for the dropping's GPE. However, both he and Maria assumed that this was the answer to the question, since they learnt that $GPE = KE$. I had earlier thought that perhaps this was a "careless" mistake. However, discussions with students' during the PT session confirmed my suspicion it was indeed an incorrect conception]</i></p> <p>Maria : so ans 0.25N</p> <p><i>[Here, we see that Maria had the wrong unit (the unit for energy is Joules), and further analysis of the log indicates this was not a "careless" mistake]</i></p>
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In sum, the discrete insights I obtained from students' protocol data are summarised in Table 5.20.

Table 5.20: Summary of "discrete" misconceptions/misunderstandings uncovered during the pilot study

Topic	Misconception / Misunderstanding Uncovered
Physical Quantities, Units and Measures	<ul style="list-style-type: none"> * 'Direction' means being able to increase or decrease in value * A scalar has direction only * A scalar has both magnitude and direction * A vector has direction but scalar has no direction (magnitude not mentioned) [T] * KM (kilometres) is the SI unit for distance [T]

	<ul style="list-style-type: none"> * The units for displacement is m/s * The units for acceleration is m/s * The unit for Work Done is J/s
Kinematics	<ul style="list-style-type: none"> * Speed and velocity are interchangeable terms * Distance and displacement are interchangeable terms * Negative acceleration necessarily implies deceleration [T] * Finding resultant force does not require vector addition * A force cannot have a negative value * Confusion between initial velocity and final velocity * Confusion on appropriate time to use * Velocity = Displacement / Time can be used to calculate displacement in all situations (even when the object is accelerating or decelerating) * There is no need to include a negative sign (-) for an object's velocity when it moves in the opposite direction * Objects accelerate in a 'step-wise' manner * The VT graph of a falling object mirrors its motion * When acceleration is not explicitly provided, it is 10m/s^2 * Distance = Speed x Time can be used to calculate distance in all situations (even when the object is accelerating or decelerating) * Time can be negative
Energy, Work and Power	<ul style="list-style-type: none"> * KE = PE is taken literally regardless of situation; KE's value will always equal PE's value * For PE = mgh, h is the distance travelled [T]

On a whole, the three cycles revealed 24 unique misconceptions/misunderstandings and, hence, it is my opinion that that I was able to gain deep insights into the students' misconceptions/misunderstandings from their protocol data.

5.4.2 Evaluation of Students' Learning Outcomes

In order to answer the second research question, which pertains to students' learning outcomes, the intervention post-test was conducted on 5th November, and scored by me. The same combined-science physics teacher (Mr Lim) who had earlier reviewed the pre-test scoring also assessed the post-test marking, and found the scoring to be consistent. Table 5.21 summarises the three group's pre-test and post-test mean scores (and standard deviation).

Table 5.21: Descriptive statistics, including variance ratio comparisons

Grouping	Mean		Standard Deviation		Variance Ratio		Hartley's Test
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre/Post Test
CG	14.36	13.07	6.24	5.76	2.17	2.99	8.38
AG	8.07	5.36	4.23	3.33			
XG	9.86	17.64	4.71	3.58			

(Critical Value for $n = 7$;
 $k = 3$; $\alpha = 0.05$)

While a mean score of 17.64 for XG appears to be low, on average, students in the XG out-improved students in CG by 9 points, and out-improved students in AG by 10 points. Hence, in percentage terms, students in XG out-improved the other two groups by at least 25%. In my opinion, the overall low marks could be an indication of the level of difficulty of the pre- and post-tests, which were based on difficult questions. A question could be difficult due to various factors, including the amount of time given for the test, the comprehension skill needed to understand the question posed (e.g. see Pollitt & Ahmed, 2001), the type of mathematics involved (e.g. see Tuminaro & Redish, 2003), as well as other non-physics demands (e.g. see Soong et al., 2009). Nonetheless, I had higher expectations for the XG students' results, and feel that perhaps their low scores were also an indication that they needed more time for learning (see Gettinger, 1984) than anticipated.

The analysis of covariance (ANCOVA; see Figure 5.9) using post-test scores as the dependent variable, the groups as the fixed factor, and pre-test scores as the covariate revealed that *post-test scores was significantly influenced by the students' groupings* ($F(2,17) = 16.913$, $p < 0.001$; effect size (partial eta squared) = 0.666). Also, it is reassuring to note that the *post-test scores was also significantly influenced by pre-test scores* ($F(1,17) = 8.694$, $p < 0.01$; effect size (partial eta squared) = 0.338). I noted with interest that the effect size (partial eta squared) of the pre-test score was less than that of the treatment effect (grouping).

Two fundamental assumptions of the ANCOVA are the assumption of independence of the covariate and treatment effect and the homogeneity of variance (Field, 2009). While we

calculated Levene's test of equality of error variances in our ANCOVA to be insignificant ($F(2,18)=3.305$, $p = 0.06$), the p-value is very close to the 0.05 threshold. Hence, I calculated the variance ratio and compared it against the critical value provided by Hartley's test (see Field, 2009, p.150-151). The variance ratio for the pre-test is 2.17, and for the post-test is 2.99. Given that the critical value provided by Hartley's test is 8.38, both the variance ratios are smaller than the relevant critical value and so we conclude that the data does not provide evidence that the homogeneity of variance assumption has been violated. Since we had already established the independence of the covariate and treatment effect earlier, the ANCOVA results appear valid.

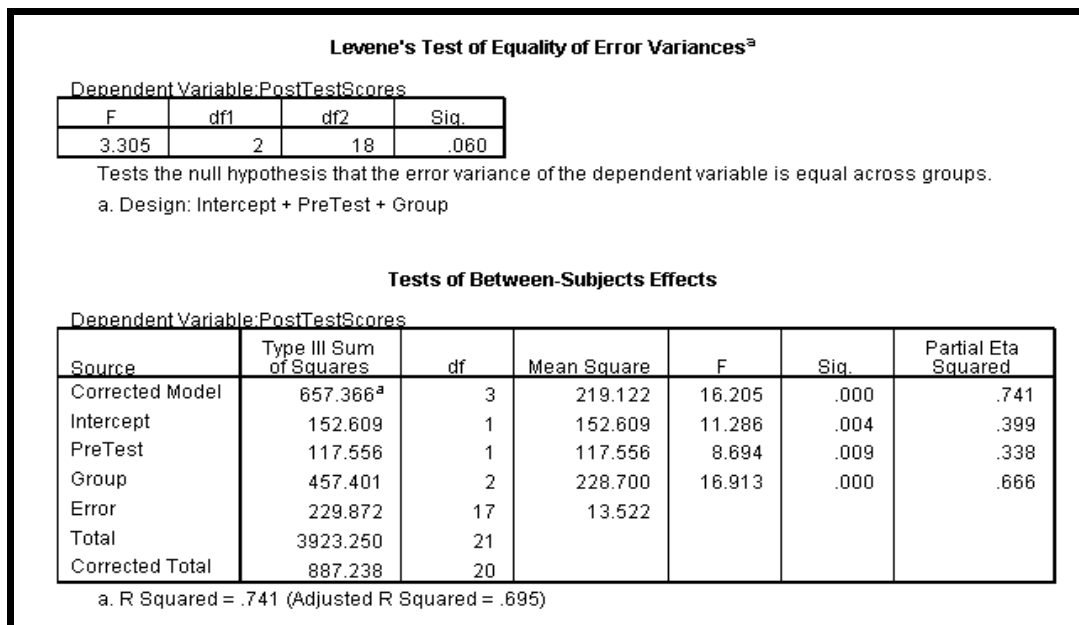


Figure 5.9: ANCOVA results

An analysis of variance test (ANOVA; see Figure 5.10) was also conducted in order to ascertain if there was a significant difference in the *mean gain in test scores* (the difference between post-test and pre-test scores) between the three groups. The ANOVA test scores that the mean gain in scores is significantly different between the three groups ($F(2,12.818) = 11.583$, $p < 0.01$; since the assumption of homogeneity of variance was violated, therefore the Brown-Forsythe F-ratio is reported).

Descriptives									
PrePostTestDifference									
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum	
					Lower Bound	Upper Bound			
Control	7	-1.2857	5.14666	1.94525	-6.0456	3.4742	-10.50	5.00	
Alternate Intervention	7	-2.6429	1.43510	.54242	-3.9701	-1.3156	-4.50	-1.00	
Experimental	7	7.7857	5.45326	2.06114	2.7423	12.8291	2.50	15.00	
Total	21	1.2857	6.32371	1.37995	-1.5928	4.1642	-10.50	15.00	

Test of Homogeneity of Variances			
PrePostTestDifference			
Levene Statistic	df1	df2	Sig.
7.390	2	18	.005

ANOVA					
PrePostTestDifference					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	450.071	2	225.036	11.583	.001
Within Groups	349.714	18	19.429		
Total	799.786	20			

Robust Tests of Equality of Means				
PrePostTestDifference				
	Statistic ^a	df1	df2	Sig.
Welch	11.203	2	9.048	.004
Brown-Forsythe	11.583	2	12.818	.001

a. Asymptotically F distributed.

Figure 5.10: ANOVA results

Given the significant ANOVA findings, further t-testing was conducted. The *t*-tests on gain scores reveal that the difference in mean gain in scores was *not significant between CG and AG* ($t=0.672$, $p=0.514$; see Figure 5.11), but was *significant between CG and XG* ($t=-3.20$, $p<0.01$; see Figure 5.12). The mean gain score is lower ($M=-1.29$, $SD=5.15$) for CG than for XG ($M=7.79$, $SD=5.45$). The t-test also reveals that the difference in mean gain in scores was *significant between AG and XG* ($t=-4.89$, $p<0.01$; see Figure 5.13). The mean gain score is lower ($M=-2.64$, $SD=1.44$) for AG than for XG ($M=7.79$, $SD=5.45$).

Group Statistics				
PrePostTestDifference	Group Type	N	Mean	Std. Error Mean
	Control	7	-1.2857	1.94525
	Alternate Intervention	7	-2.6429	.54242

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
PrePostTestDifference	Equal variances assumed	5.925	.031	.672	12	.514	1.35714	2.01946	-3.04289	5.75718
	Equal variances not assumed			.672	6.927	.523	1.35714	2.01946	-3.42829	6.14257

Figure 5.11: T-testing between CG and AG

Group Statistics					
	Group Type	N	Mean	Std. Deviation	Std. Error Mean
PrePostTestDifference	Control	7	-1.2857	5.14666	1.94525
	Experimental	7	7.7857	5.45326	2.06114

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
PrePostTestDifference	Equal variances assumed	.666	.430	-3.201	12	.008	-9.07143	2.83413	-15.24648	-2.89638
	Equal variances not assumed			-3.201	11.960	.008	-9.07143	2.83413	-15.24876	-2.89409

Figure 5.12: T-testing between CG and XG

Group Statistics					
	Group Type	N	Mean	Std. Deviation	Std. Error Mean
PrePostTestDifference	Alternate Intervention	7	-2.6429	1.43510	.54242
	Experimental	7	7.7857	5.45326	2.06114

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
PrePostTestDifference	Equal variances assumed	41.294	.000	-4.893	12	.000	-10.42857	2.13132	-15.07231	-5.78483
	Equal variances not assumed			-4.893	6.827	.002	-10.42857	2.13132	-15.49433	-5.36281

Figure 5.13: T-testing between AG and AG

In summary, all the relevant statistical tests (ANCOVA; ANOVA and t-test on gain scores) conducted show statistically significant improvements for XG. Hence, controlling for initial ability, there was a significant difference in post-test scores between the three groups. Statistical analysis indicated that students who underwent the intervention obtained significantly higher post-test scores – an improvement of more than 25% – as compared to students in the control or alternate intervention groups. Hence, it can be said that as a result of immersion in my intervention, the students’ understanding of physics concepts improved by a large extent.

5.4.3 Students' Evaluation of the Intervention

In order to evaluate the extent to which the students were comfortable with my intervention (i.e. to answer the third research question), I elicited students' feedback via a focus group semi-structured discussion session, individual semi-structured interviews (prior to them

knowing their pre-test/post-test results), as well as through their response to a short survey after every CMCPs session. The data collection procedure and analysis methods are summarised in Table 5.22.

Table 5.22: Qualitative data collection and analysis methods to elicit students' evaluation of the intervention

Data collected	Main questions asked	Procedure
Focus group discussion	* Were you comfortable in the learning environment? Why? * Which areas made you feel comfortable? Why? * Which areas made you feel uncomfortable? Why?	Audio recorded and reviewed numerous times, and appropriate portions were transcribed
Individual interviews	* Now that you have been involved in this revision method, what are your views on using computers for learning? Like it? Dislike it? Why?	Recorded and 100% transcribed (since the interview was conducted via text-chat)
Short survey responses (after every CMCPs session)	* How do you feel about working with a partner via the computer to solve Physics questions? <input type="checkbox"/> Very Comfortable <input type="checkbox"/> Comfortable <input type="checkbox"/> Neutral <input type="checkbox"/> Uncomfortable <input type="checkbox"/> Very Uncomfortable	Recorded and statistically analysed

The aggregated students' responses are given in Table 5.23. Generally, the students were initially not entirely comfortable in the learning intervention. However, by the third session, they were more comfortable with the environment, mainly because they could see its benefits. Interestingly, the main area that made many students feel comfortable was the "chat room", where they felt that they had created their "own logic that don't make sense" and "gave a lot of funny formulas" that I then corrected. There were three main areas where the students were uncomfortable with in our learning intervention. Firstly, Ziki initially felt uncomfortable having to type out his explanations when he was used to speaking directly to each other (Sarsi concurred with this view). Secondly, the majority of students who worked in groups of three felt that it was "very difficult to communicate" in a three person group (and this was verified by their survey responses). Thirdly, Mumo felt that if his "secret partner" knew his identity (which is possible given the small class size), he would "hold back" from revealing what he

thought, for fear of embarrassing himself. Nonetheless, after the third session, the students were more comfortable with the intervention, and saw the benefit of text-chatting instead of speaking directly with their classmates while problem-solving.

Table 5.23: Aggregated students' response (spelling and grammar mistakes have been corrected)

Student Names (Anon)	Focus Group Response Snippet [Conducted in a computer laboratory]	Individual Interview Response Snippet [Conducted via text-chat]	Survey Response [Likert scale of 1 to 5, with 1 being very comfortable]
Sarsi	The first time it might be quite awkward because [it requires] explaining through words, and normally I do it through talking to people. First time of course it is uncomfortable, but out of 10, I'd rate [the first time a] 6 out of 10 that it is comfortable actually, as we are all used to seating at home and [text] chatting.	It's beneficial [as] it really corrected us. Just simply through WORDS that we type it with our OWN HANDS. It's powerful.	Session 1: 2 Session 2: 3 Session 3: 1
Ziki	At first...like...very nervous, then after the second or third time, its... like...ok.	Quite like it [as] it is a new way of learning [and also like] the way we answer the questions.	Session 1: 1 Session 2: 2 Session 3: 1
Maria	It's different from the [traditional] class when we use computers; its rather more comfortable [in this setting].	Yes rather like it. It [is] something [like a] new way of discussing the question.	Session 1: 2 Session 2: 2 Session 3: 2
Taki	The environment is very good because there is air-con!	Neutral. Sometimes when I am really stuck in that question, I will not know what to do. But I think should continue [with the intervention]	Session 1: 2 Session 2: 3 Session 3: 3
Gabo	After a few rounds, gradually it gets better.	They [the intervention sessions] are okay, as long as it helps, anything is ok as long as it helps me.	Session 1: 2 Session 2: 2 Session 3: 2
Mumo	When you get used to it...you can communicate well...like...you feel better.	I like it but it is not good without the prescriptive [tutoring sessions]. They are like one process. It is different from learning in class and very interesting and creative.	Session 1: 2 Session 2: 2 Session 3: 1
Dino	Dino did not answer the question specifically. Instead, she responded with: "At first I didn't want to come because I	I like it because I think it has really helped me improve. Because I cleared my misunderstanding and I think you taught us the right way. The method you	Session 1: 1 Session 2: 2

	thought I'd waste my time. But now, I think it make me...get higher marks, I think."	used is correct. The log when we discuss with a partner first, then you analyse all our mistakes and print it out for us.	Session 3: 1
Summary	Students generally got more comfortable as they got used to the intervention.	Students generally feel that the intervention has helped them improve.	Twosome average: 1.73 Threesome average: 2.17 Overall average: 1.86

On the whole, the students reported that they appreciated the intervention and felt they had learnt much. Every student requested to continue with the intervention for the coming academic year mainly because they felt that the intervention had helped them improve, and many students even suggested that chemistry revision could be done the same way. Hence, despite their initial reservations, the students were eventually comfortable enough with our intervention such that they were willing to continue with it.

5.4.4 Teacher's Evaluation of the Intervention

When the pilot study was concluded, Mr Ng was shown the PT 'notes' that were used during PT sessions (these notes were also handed out to the students), and asked to comment on the recorded misconceptions/misunderstandings. Out of these 24 misconceptions, he identified 20 misconceptions as being "unexpected", which was to say that he either had never seen such a misconception, or was surprised that a particular student still had a particular misconception. When he reviewed the students' logs which were shown in the PT 'notes', he immediately recognised that a key difference between our intervention and traditional revision practices was that our intervention "is informing the processes before they came to the solution itself. I mean, in the classroom written work, they just write the final solution – the final product of what thinking processes have went through their mind. But here, you really can see what

went through their mind, what are the ideas that came through their mind, consolidated together before they came up with the final answer. This is something I find teachers are unable to see". It was heartening for me to note that while he was assigned to teach a different physics class for the next academic year (and hence, was not expected to be directly involved in the pursuit of the intervention), he sent an email to the school Principal, Head of Department for Science (Ms Er), and myself, stating that he would want to "work closely with you [i.e. the researcher], together with Ms Er, when the new academic year starts, so that gradually I can have some ownership of the ICT-assisted learning of physics intervention programme for next year's batch of weak 3E1 pure physics students. Then, there will be some continuity and follow-up in your intervention". Hence, I believe that from the teacher's perspective, the intervention was deemed useful and worthy of his personal involvement and evaluation.

5.5 Discussion of Findings

5.5.1 Improvements in Learning Outcomes and Alternative Explanations

Based on the quantitative and qualitative data analysis, my intervention for physics revision appears to be effective in helping the students revise physics concepts. The students also appear to appreciate revising physics concepts using the intervention I introduced. It seems, therefore, that I have the basis for an effective, practical way of helping students revise physics, while also helping Mr Ng gain deeper insights to his students' conceptions and thought processes. However, alternative explanations for why the students improved can be offered. For example, one possible reason for why XG students performed better for the post-test could be that they had been practicing and revising physics concepts continuously prior to the post-test and as a result, understood the concepts covered. After all, time-on-task has long been accepted as a predictor of learning outcomes (Carroll, 1963; Bloom, 1971; Fisher & Berliner, 1985), albeit not always sufficient (Cornbleth, 1980) and the relationship is not necessarily linear (Fredrick & Walberg, 1980). Linked to time-on-task is the possibility that these students could have high aptitude for physics and, hence, given the additional time-on-task, were able to vastly improve their understanding. Another possible reason could be due to my mere

presence, since I'm a researcher from the university that, in partnership with the Singapore Ministry of Education, provides for the GCE examinations that the students would take. Hence, the students may have been more inspired and motivated to work hard given my mere presence. Linked to motivation, yet another reason could be due to novelty effects of working anonymously with fellow students in a computer-mediated environment. After all, the students acknowledged that, from an educational perspective, this was the first time they learned *through* – and not *from* – computers, which many found “Very fun!” I shall now address these alternate explanations in turn.

I agree that, in general, time-on-task is a good predictor of learning outcomes. However, in this situation, the students took the pre-test merely one week after their end-of-year physics examination. Since it is reasonable to assume that the students would have worked hard up to the final day in preparing for that examination, then the time-on-task argument is weakened. As for the possibility of the students having high aptitude for physics, two of the XG students have consistently failed physics, and were earmarked to drop the subject at the start of the next academic year (although they were not told of this plan during the pilot study period). Hence, the aptitude argument is not valid. With regards to the effects of presence, it is unlikely that the students were affected by my mere presence. In fact, I found the students to be quite nonchalant in my presence. In addition, in the *Informed Consent Form* that the students signed, they were advised that there can be no guarantee of the learning intervention's effectiveness. However, I cannot totally disregard novelty effects and, hence, a temporal/longitudinal study would need to be conducted to test this possibility.

5.5.2 Discussion on Whether Deep Insights are Assessable via Traditional Testing

While I have shown that analysis of students' CMCPs attempts reveal deep insights about students' knowledge base and thought processes, it may be suggested that similar insights might be gleaned merely from traditional means, especially students' test scripts. In an exam, students provide more 'workings' as an attempt to maximize their scores, since marks are given for correct 'workings' despite an incorrect final answer. In my opinion, while students'

test scripts (and other similar exercises including answers to 'ten-year series' questions) may offer teachers some insights into students' knowledge base and thought processes, the granularity of the insight is much more coarse when compared to the information obtained via CMCPS. This is because students often do not record (on paper) their explanations or considerations for solving questions posed. Given the lack of details, it is often difficult to distinguish between a 'careless' mistake, a lack of knowledge, or a misconception/misunderstanding. In other words, the extent or reason for their mistakes is often difficult to ascertain. For instance, if a student does not provide any answer to a test question, or provides a correct answer to one part, but an incorrect answer to a related part (i.e. the complete answer is inconsistent), what should we assume? Should we assume that they did not understand the question posed? Or do we assume that they ran out of time? Or perhaps they could not remember the formulas to be used? Or maybe they do not know the concepts involved? Figure 5.14 provides an instantiation of such a dilemma. Taken directly from a term test taken by a student in 4E1, the student was asked (in Part A) to find the pressure at Point A. The student stated that the pressure was 750mm Hg, when the answer should have been 0mm Hg. Viewed individually, the most likely deduction is that this student does not recognise that there is no pressure acting on the liquid mercury at the top of a simple mercury barometer set-up, since the top is a vacuum. However, a related question (in Part B) asked the student to calculate the pressure at Point B, in which the student obtained the correct answer by first calculating the length of mercury in which Point B was under (" $85 - 52 = 33\text{cm}$ ") before providing the correct answer (330mm Hg). Viewed individually, it appears that this student understands the concept of pressure in a liquid column. However, viewing the combined answer provided for both Parts A and B, the student's answer appears inconsistent, and illustrates that it is actually rather difficult to obtain deep insights into students' knowledge base and thought processes via test scripts.

A3 Fig. 3.1 shows the set-up of a simple mercury barometer. The atmospheric pressure is 750 mm Hg and the density of mercury is 13.6 g cm^{-3} .

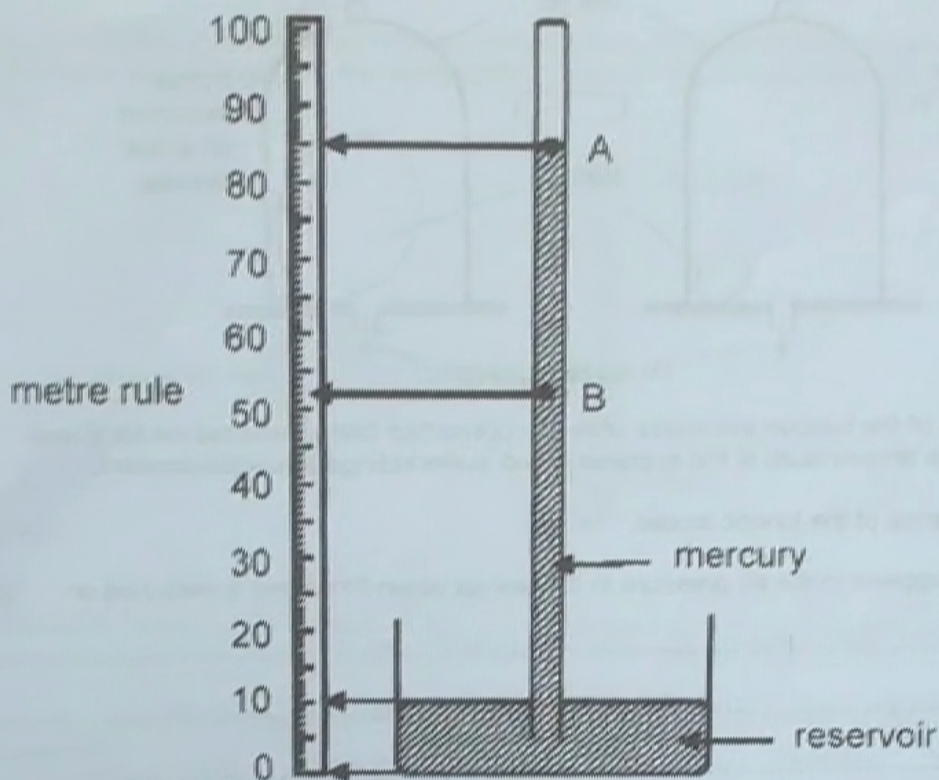


Fig. 3.1

(a) Determine the pressure at point A in mm Hg. [1]

0

$$85 - 10 = 75 \text{ cm}$$

$$p = 750 \text{ mmHg}$$

(b) State the pressure at point B in mm Hg and calculate its pressure in Pascal. [3]

3

$$85 - 52 = 33 \text{ cm}$$

$$P_B = 330 \text{ mmHg}$$

$$= 0.33 \text{ m} \times 13600 \text{ kg/m}^3 \times 10 \text{ N/kg}$$

$$= 448 \quad 44900 \text{ Pa} \quad (3.5)$$

Figure 5.14: A student's inconsistent response to a test question

5.5.3 Key Constructs that Enabled this Intervention

As I have argued in Chapter Two, the dimensions in activity theory can provide the logical connectivity and relevant constructs for describing artefact-mediated activities. Hence, I will be using the dimensions provided for by the Activity Theory model in order to describe the key constructs that, in my opinion, enabled this intervention (and the results it obtained).

Figure 5.15 provides a typical depiction of the Activity Theory model, while Figure 5.16 provides an instantiation based on the pilot study. In order to provide a more vivid description of the working of the intervention so as to assist readers in understanding the context in which the teaching and learning took place, I sub-divided the Activity Theory model into its nine interacting components, and provide descriptions and illustrations detailing the pilot study for each of these nine interacting components.

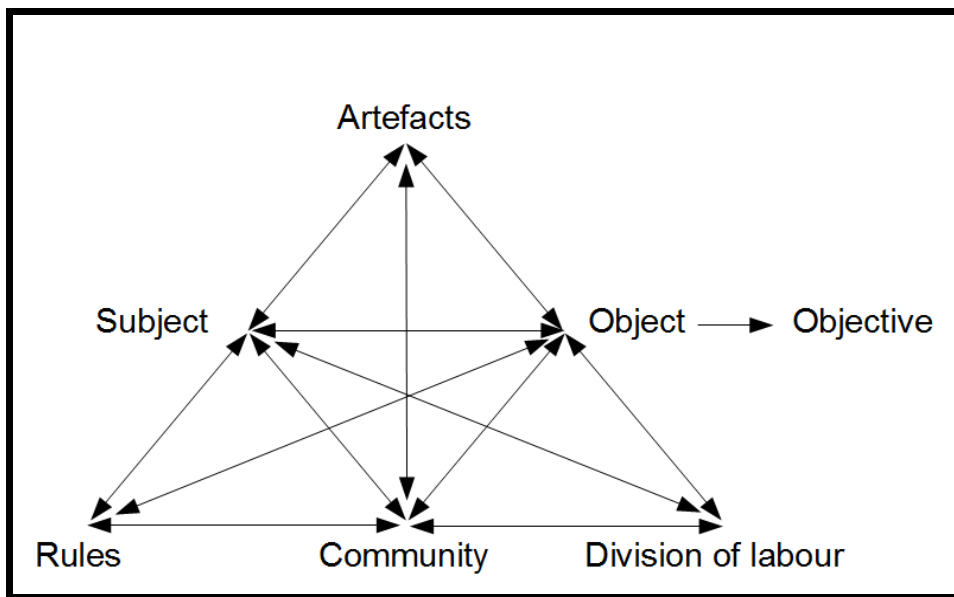


Figure 5.15: Activity Theory model

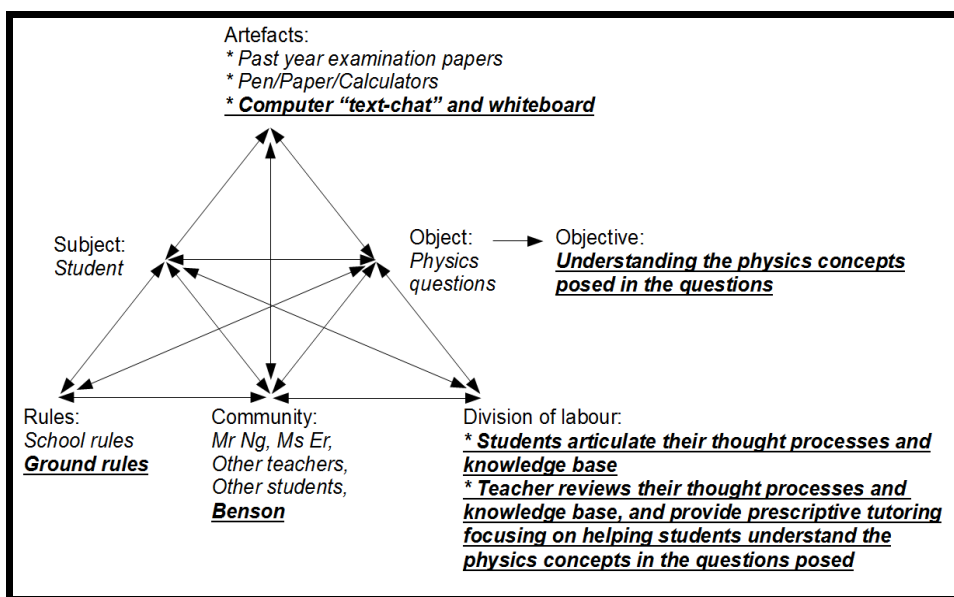


Figure 5.16: Activity Theory model based on an instantiation of the pilot study

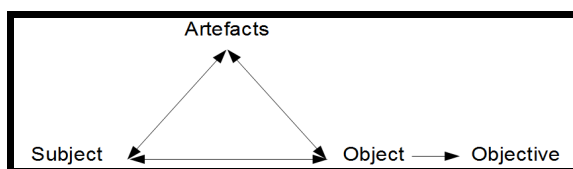


Figure 5.17: Student-Artefact-Object interaction

Figure 5.17 shows the student-artefact-object interacting components, which may be used to draw attention to a student's instinctive objective when s/he uses a particular artefact. In the context of Bartley Secondary School, students use computers in the computer laboratory to answer multiple-choice or survey questions. On occasions, they use the computers there for playing games and online socialising purposes, such as instant (text) messaging with their friends. The intervention required the students to attach a different purpose for using the computer. Instead of using computers to receive feedback (as in the case of answering topic-based multiple-choice questions), provide feedback (as in the case of answering survey questions), or for entertainment purposes (as in the case of playing games or online socialising via text-chatting), I explained to the students that the chat-logs that are automatically generated by instant messaging software (such as MSN or NetMeeting) can provide me with deep insights into their physics knowledge base and hence, misconceptions. If I knew where their physics misconceptions lay, I may then provide them with instruction that would lead them to normative views, thus helping them to get better grades for their physics tests and exams. In addition, I explained to them that it was entirely possible that they learn from one another, as other students before them had discovered. Hence, I aligned the students' (the *subject*) objective of using computers (the *artefact*) for solving physics questions (the *object*) to be the same as mine – for the purpose of peer discussion and providing me with a record of their discourse so that I may conduct 'prescriptive tutoring' such that they would understand the concepts probed by the questions posed (the *objective*). This process was more tedious than I had initially thought, and I found myself needing to repeat the intention for using computers during the CMCPs sessions. In my opinion, the successful implementation of this pilot study required students to understand how computers served my intended purpose, and in the case of this pilot study, I believe they did only after the first CMCPs-PT cycle. In

addition, because I knew through experience that students placed more emphasis on obtaining correct answers to questions posed than on understanding the fundamental physics concepts raised by the questions, I took some time to explain to the students that getting the correct answer was meaningless if they do not understand the physics concepts involved because while questions and question formats can change, the fundamental physics principles do not. I told them that a fixation on correct answers was like trying to memorise thousands of question combinations, which was difficult and unnecessary, when all that was needed was a proper understanding of the physics concepts in question. In other words, I spent some time motivating students to change their objectives when confronted with questions; instead of seeking to obtain the correct solution, they should check that they understand the physics concepts probed instead.

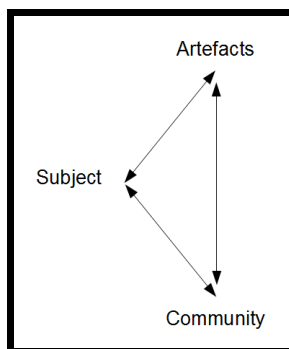


Figure 5.18: Student-Community-Artefact interaction

Figure 5.18 shows the student-community-artefact interacting components, which may be used to draw attention to what a student and his/her community perceives as the value of computers (a shared *ideal* perspective). In the context of the school, computers were seldom used in a teaching and learning context. If they were used for teaching and learning, it did not require connectivity between two computers in the laboratory, since students were meant to interact with the computers, and not with each other. I discovered that if the credentials used to access the computers were student-based, inter-computer connectivity was blocked. Due to the default computer policy settings in the school, inter-computer connectivity was only allowed if the login credentials were either a teacher's or an administrator's. As such, I spent some time with Mr Das (the school's IT technician) to ensure that the computers could connect

to one another. Eventually, Mr Das had to specially configure and provide me with a limited-access teacher's login account, which we used for logging into the machines so that the computers could connect with one another, while preventing access to sensitive intranet materials such as marking reports and test scripts. In my opinion, this exercise shows that from an *ideal* (as opposed to *material*) perspective, the school community (the *community*) perceived that students (the *subject*) best learn *from*, and not *through*, computers (the artefact), and this was a perspective I worked hard at changing.

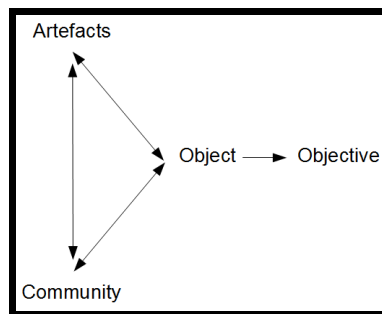


Figure 5.19: Community-Artefact-Object interaction

Figure 5.19 shows the community-artefact-object interacting components, which may be used to draw attention to the community's instinctive objective when using an artefact. In the context of teaching and learning in the school, while computers (the *artefact*) have been used to quiz students on their subject knowledge base via multiple-choice questions (the *object*), it had never been used for discourse purposes (the *objectives*). Hence, I needed to spend time explaining to the Principal, Vice-Principal, and Head of Department for IT (the *community*) why I needed to use the computer laboratory, and why I needed extensive technical support from Mr Das, especially during the initial testing periods.

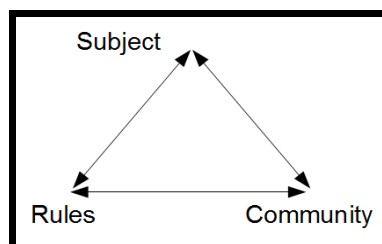


Figure 5.20: Subject-Community-Rules interaction

Figure 5.20 shows the subject-community-rules interacting components, which may be used to draw attention to how a student (the *subject*) is to behave within the school community (the *community*). Based on my observations in the school, the rules during classroom lessons were such that students were expected to keep quiet during lessons, and speak only when spoken to (the *rules*). However, for my intervention, I wanted to encourage student-generated discourse both during the CMCPS and PT sessions. Naturally, students discourse during CMCPS occurred via the computer and given their prior experience with text-chatting (and my 'activity training'; see section 4.3.3), I was confident that meaningful discourse would take place then. I was more concerned about the PT sessions, since from a classroom set-up perspective, it was very similar in structure to traditional classroom lessons. Hence, my PT 'notes' and lessons were intentionally designed such that students' views were explicitly elicited by featuring students' chat data, which I found served as an excellent resource that would get students talking about (and even defending) their preconceptions.

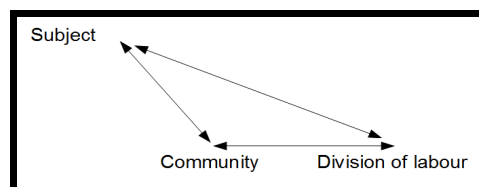


Figure 5.21: Subject-Community-Division of labour interaction

Figure 5.21 shows the subject-community-division of labour interacting components, which may be used to draw attention to what a student expects a teacher to do within the school community. Based on my experience, students' typically expect teachers to provide them with 'model answers' to questions posed. Because I wanted students to focus on understanding the physics concepts probed by the questions, rather than memorising a 'model solution', I emphasised to the students that my main job was to help them understand the physics concepts probed in the questions, and also to identify and correct their misconceptions, and that it would fall on their shoulders to ensure that they could derive at the solution to the questions posed. While I still provided answers, it was generally less detailed than what they

were generally used to receiving. I believe such a division of labour motivated students to shift their focus from memorising to understanding.

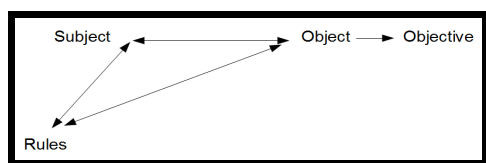


Figure 5.22: Subject-Rules-Object interaction

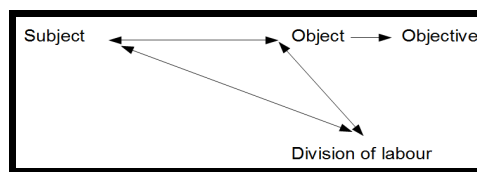


Figure 5.23: Subject-Division of labour-Object interaction

Figures 5.22 and 5.23 shows the subject-rules-object and subject-division of labour-object interacting components, which may be used to draw attention to the ground rules and expected conduct that I had to establish with the students with regards to the objective of getting them to understand the physics concepts probed by the questions posed. Given my prior experience in conducting such sessions (see also Mercer, 2000), I felt that the ground rules (the *rules*) would provide students with a guide on expected and acceptable behaviour (such as asking 'why' and providing reasons for disagreements; the *division of labour*), given that our (the students' and my own) objective was for the students (the *subject*) to address the questions posed (the *object*) such that peer discussion could occur, enabling me to glean meaningful insights that would be helpful for prescriptive tutoring (the *objective*). I observed that some students were quite strict with following the ground rules, while others were more *laissez faire*. Nonetheless, it is my opinion that the ground rules, as well as my physical presence in the computer laboratory, served to keep the students on task and generally well behaved.

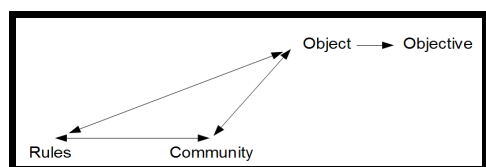


Figure 5.24: Community-Rules-Object interaction

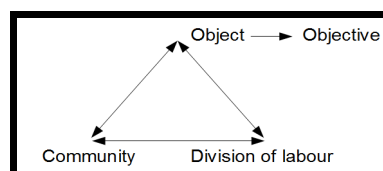


Figure 5.25: Community-Division of labour-Object interaction

Figures 5.24 and 5.25 shows the community-rules-object and community-division of labour-object interacting components, which may be used to draw attention to the new 'rules' and

'duties' that I brought into the school as a result of the conduct of the intervention. Prior to my intervention, while the school community (the *community*) was familiar with using questions (the *object*) during revision sessions, no one had conducted or even considered using computers (the *artefact*) as a means for student discourse. Subsequently, reviewing students' discourse (the *division of labour*) so that prescriptive tutoring might occur was a new concept. Additionally, focus had predominately been on helping students to obtain correct answers to questions posed, and a focus on using sound physics concepts to answer questions (the *objective*) was not common. The main criteria (the *rules*) made known to me (by the Principal and Ms Er) was that students' test scores should improve as a result of involvement in the intervention, and this criteria motivated me greatly.

In sum, many important elements had to be in place in order to successfully implement the pilot study (and the positive results it obtained). By giving close consideration to the various dimensions provided by the activity theory model, I believe this intervention (and its resulting positive results) may be experienced by another researcher/teacher.

5.5.4 Evidence of Peer Discussion Leading to Cognitive Development via a Piagetian and/or Vygotskyan account of Cognitive Development

Table 5.24 provides an example of protocol data taken verbatim from a student-dyad during the third CMCPS session. The snippet shows how Mumo and Sarsi collaboratively solved the problem while they worked within each other's zone of proximal development (ZPD; see Vygotsky, 1978) or "intermental development zone" (IDZ; see Mercer, 2000). Again, when appropriate, I provide my comments in square brackets ([...]) to aid the reader in understanding the context of the students' problem solving attempts.

Table 5.24: Suggestion of ZPD/IDZ learning

Question Posed	Discussion Snippet
John was riding on a bicycle, travelling at a constant speed of 2 m/s. Suddenly, he	Mumo: use graph?? [Mumo tentatively suggests to draw a graph in order to obtain the solution] Sarsi: ah...?

<p>spotted a cat in his path, and immediately pressed on the brakes. If he comes to a stop after 2 seconds, and the total mass of John and the bicycle is 80kg, what is the average heat lost from the bicycle's brakes?</p>	<p>Sarsi: why</p> <p>Mumo:</p> <p>Sarsi: why</p> <p><i>[Sarsi questions the reason behind drawing a graph, and Mumo's response "....." –which the students use to mean "I'm thinking"– imply that he merely suggested to draw a graph without a clear purpose or strategy]</i></p> <p>Sarsi: energy heat lost = $\frac{1}{2} \times m \times v^2$</p> <p>Mumo: what should we find firstly??</p> <p>Mumo: ok</p> <p><i>[Here, Sarsi states (correctly) that the heat energy lost is equal to the initial kinetic energy possessed by the bicycle (with John on it). Mumo agrees with this approach.]</i></p> <p>Sarsi: = $\frac{1}{2} \times 80 \times 4 = 160 \text{ J?}$</p> <p><i>[Using the correct formula, Sarsi obtained the answer for the total energy in the system, which he thought was the answer to the question (it isn't)]</i></p> <p>Mumo: ya</p> <p>Mumo: divided by 2s</p> <p>Mumo: 80 J/s</p> <p><i>[Mumo states that he understands Sarsi's rationale, and demonstrates this by extending Sarsi's solution in order to obtain the correct answer]</i></p> <p>Sarsi: why?</p> <p>Mumo: average heat lost</p> <p>Sarsi: average heat lost...?</p> <p><i>[Sarsi does not understand Mumo's workings, and Mumo explains that he "divided by 2s" as the question asked for the "average heat lost"]</i></p> <p>Sarsi: what is the meaning of it</p> <p>Sarsi: ok... i think i get it</p> <p>Sarsi: get the teacher</p> <p>Sarsi: yay!!!!!!</p> <p><i>[Initially, Sarsi did not understand why there was a need to divide his initial answer of 160J by 2s. However, he very quickly realised that average heat lost in this context meant heat loss per second, and called for the first author to verify his understanding]</i></p> <p>Mumo: 80 Watts</p>
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	[Mumo is correct; J/s is actually Watts]
	Sarsi: smart boy.

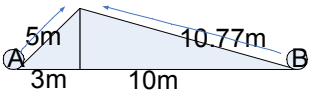
In my opinion, the snippet provided in Table 5.24 strongly suggests ZPD/IDZ learning. Without Sarsi’s initial suggestion that the heat energy lost is equal to the initial kinetic energy possessed by the boy/bicycle, Mumo might not have obtained the solution, and without Mumo’s interjection that the average heat lost implied heat loss per second, Sarsi would have obtained an incorrect answer. It is my belief that because the students operated within each other’s ZPD/IDZ, they were successful in their collaborative problem-solving and knowledge negotiation process. I note with interest that after the CMCPS session, Sarsi wrote on his survey form that “I didn’t know J/s = Watts, now I know it”, and was reminded that,

Any function in the child’s cultural development appears twice, or in two planes. First, it appears on the social plane, and then on the psychological plane. First, it appears between people as an interpsychological category, and then within the child as an intrapsychological category. This is equally true with regard to voluntary attention, logical memory, the formation of concepts, and the development of volition (Vygotsky, 1978, p. 163).

Table 5.25 provides an example of protocol data taken verbatim from the same chat log as Table 5.24. In my opinion, the snippet shows learning taking place from a ZPD/IDZ as well as a Piagetian (conflict/resolution) account of cognitive development.

Table 5.25: Suggestion of ZPD/IDZ as well as Piagetian (conflict/resolution) account of cognitive development

Question Posed	Discussion Snippet
2) Two balls (A and B) of mass 1kg	Mumo: I got it
each were pushed up a hill as shown	Sarsi: loll...
below. What is the <i>work done on Ball</i>	Mumo: mgh!!
<i>A and Ball B</i> by moving them from the	Mumo: ???
bottom to the top of the hill?	[After both students thought about the question for a while, Mumo suggested

	<p>that the solution to the question is actually to find the gravitational potential energy gained by Ball A in order to find the work done on Ball A]</p> <p>Sarsi: work done la... not energy</p> <p>[Here, Sarsi asserts strongly ("la" is a colloquial expression used to explicate a statement) that Mumo's suggestion is incorrect, since the question asked for "work done" and "not energy"]</p> <p>Mumo: same what</p> <p>[Mumo's utterance "same what" is a direct and sharp response to Sarsi's assertion that work done and energy are not equivalent]</p> <p>Sarsi: work done = dist x force energy = mgh/ 0.5mv²</p> <p>Sarsi: OH</p> <p>Sarsi: both Jolues</p> <p>Sarsi: ok</p> <p>Sarsi: can</p> <p>Sarsi: i get it</p> <p>[Because of the conflict, Sarsi used unit analysis and found that work done, gravitational potential energy, and kinetic energy all has the same unit, "Joules". Hence, work done and energy may be equivalent]</p>
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It is my view that the snippet provided in Table 5.25 strongly suggests learning by way of conflict and resolution. Initially, Sarsi asserted strongly ("work done la... not energy") that Mumo's suggestion that the *work done on Ball A* could be obtained by finding the gravitational potential energy it gained was incorrect. The assertion drew a direct and sharp response from Mumo ("same what"), which resulted in Sarsi using unit analysis to verify that Mumo was indeed correct (work done, just like gravitational potential energy or kinetic energy, is a type of energy). He realised that both work done and gravitational potential energy and kinetic energy have the same unit ("OH...both Jolues [sic]") and so he understood the rationale behind Mumo's suggestion. Here, it can be seen that "[c]riticism is born of discussion and discussion is only possible among equals: cooperation alone will therefore accomplish what intellectual constraint [caused by unquestioning belief in an adult] failed to bring about" (Piaget, 1932, p. 409). I conjecture that if a teacher had told Sarsi that work done and gravitational potential

energy or kinetic energy are equivalent in specific settings, he would have accepted it as a fact, and not attempt for himself the unit analysis that he performed in order to resolve the conflict. After all, this had happened earlier, when Ziki told Sarsi that “cher...say dorection have negative” (see Table 5.11). The reader might be interested to know that several weeks after this session, I bumped into Sarsi at school and casually asked him if he thought work done and potential energy are equivalent, to which he replied, “Of course, same unit [Joules] what”.

5.6 Chapter Summary

In this chapter, I described the design, implementation and evaluation of my pilot study. I showed that the intervention provided deep insights into students' misconceptions and misunderstandings, which allowed me to conduct 'prescriptive tutoring' centred on the students' specific misconceptions and misunderstandings. As a result of the intervention, their physics grades improved significantly, and the students reported that they were fairly comfortable with the intervention despite their many years of exposure to other (less dialogic) approaches. The study also revealed that their physics teacher (Mr Ng) found the information gleaned from the CMCPS sessions to be insightful and useful, and he reported that he would want to try out the intervention in his physics class for the academic year 2009, even though his class was not earmarked for involvement in the study.

Given the positive results of this pilot study, the school had given me permission to involve the entire 4E1 class in my revision intervention for the entire 2009 academic year. In that setting, novelty, motivation, aptitude and other such factors would have been normalised given the temporal/longitudinal nature of the research work. Naturally, conducting the intervention during regular term time and during standard curriculum hours require some changes made to the implementation of the intervention, and Chapter Six provides a such discussion on the design, implementation and evaluation of the main study.

CHAPTER SIX

MAIN STUDY DESIGN, IMPLEMENTATION & EVALUATION

This chapter focuses on the design, implementation and evaluation of the main study. I start the chapter by stating my research questions, some of which are similar in focus to the pilot study (e.g. whether there had been improvements in students' physics understanding, resulting in improved test scores), and others which have surfaced as a result of the research implications of the pilot study (e.g. whether students' specific difficulties when solving physics questions could be derived from the CMCPs protocol data). Thereafter, I provide a discussion on the changes made to the intervention in order to conduct it during term time and within curriculum hours in school based on a whole class setting. Next, I describe the procedure and time-line for the main study. I then provide a discussion on my data collection and analysis, elaborating how the research questions were answered in the study. Thereafter, I provide a discussion of the findings of this main study, including a description of specific difficulties the students faced when solving physics questions, as well as a discussion on fostering dialogic pedagogical classroom activities.

6.1 Research Questions

The main study reported in this chapter is the second iteration of my design experiment and was made possible given the positive results of the pilot study as reported in Chapter Five. From the perspective of the school community (especially the Principal, Vice-Principal, Head of Department for Science, and students of 4E1), their objective for being involved in the intervention essentially centred on our joint belief that the students' results would improve as a result of involvement in the intervention. This belief was supported initially by the theoretical foundations embedded within the intervention (as discussed in Chapters Two and Four), and later by evidence from the pilot study. Despite the success of the pilot study, I recognised that the involvement of an entire class of physics students would certainly be more complex than merely involving a small group of students. Hence, a key research question I

wanted to answer was whether the students' results would improve as a result of involvement in the intervention in spite of a larger, class-based setting. I no longer needed to discover if I were able to obtain deep insights into the students' misconceptions/misunderstandings from their protocol data, as the pilot study had convincingly shown that it was indeed the case. Given the longitudinal nature of the main study, I also wanted to evaluate the students' interest in physics, their perceptions on whether group work helped them in solving physics problems, and their impressions of the intervention in general. In addition to evaluating the intervention from a *students' consequence* perspective, I also wanted to evaluate the intervention from a *teacher's consequence* perspective. Towards that end, I wanted to obtain the teacher's personal reflection of being involved in the intervention. Also, I wanted to answer questions that arose as a result of the findings of the pilot study. Hence, in short, the overarching objective of the main study was for me to answer the following research questions:

- (i) As a result of immersion in my intervention, to what extent did students' learning outcomes improve?
- (ii) What were the key themes that stood out for the teacher, when she reflected on her involvement in the intervention?
- (iii) How, if at all, had the students' physics revision practices changed after the intervention?
- (iv) How comfortable were the students with the intervention, given their years of exposure to other approaches?
- (v) What were the specific difficulties that students faced when solving physics problems?

6.2 Pre-intervention Activities and Considerations

While the pilot study was conducted during term time, it was conducted during the final weeks of the academic year, when teachers are usually more focussed on administrative endeavours, such as the annual students' promotion exercise and recommendations on what subjects should be dropped by which students. As such, while the students still had regular lessons during 'standard curriculum time' (SCT; from 7.30am to 1.30pm), there were no 'after curriculum time' lessons (ACT; usually from 2pm to 3.30pm). ACT lessons are especially

common for secondary three and four students, and it is not unusual for students to attend ACT lessons three times a week. As the intervention for the pilot study was conducted on a daily basis consecutively during ACT time, we had no restrictions on a fixed ending time since the students did not need to rush off to another lesson when the bell rang. As we had no fixed ending time, I usually ended the CMCPs sessions when all the students had completed the questions, or when I felt that the students had reached the tail-end of their productivity cycle (which I found to be about one and one-quarter hours). Given the dialogic nature of the PT sessions, each PT session usually lasted about one and three-quarter hours.

With the beginning of the new academic year (there are four academic terms per year, and each term lasts ten weeks), the students' timetables (both SCT and ACT) were filled with lessons. Additionally, the maximum consecutive number of periods given per lesson was only two. Since each period is only 30 minutes, it was impossible to replicate the pilot intervention design for the main study. Also, given that most of the students were taking seven subjects for their GCE 'O' level examinations, there was less than one hour of instructional time available per day per subject. The total time available for subject instruction was even lower given the students' involvement in other co-curricular activities, such as participation in the school band or peer counselling.

As I was working within the constraints of the school, no special concessions were given for physics. Hence, we (Ms Er and I) decided to conduct the CMCPs sessions during ACT and the PT sessions during SCT. Naturally, this would mean that the PT sessions would be stretched over different SCT physics lessons (e.g. four periods across different days), which I did not feel was ideal but was nonetheless unavoidable. Given the students' already packed ACT schedule, we could only schedule three CMCPs sessions for the first academic term (students' schedules are assigned on a per-term basis). Initially, I had planned to conduct at least five CMCPs-PT cycles per academic term, with each CMCPs-PT cycle covering one physics topic (there are 22 examinable topics). However, this was not possible given the students' schedules, and so I worked my intervention around what was possible and not what was ideal. Additionally, the

top two physics students (Xian and Chan) requested at the start of the year to be excused from taking part in the intervention. They commented that they had consistently scored very high marks for all their physics tests and exams, and did not think that the intervention could help them further (since they had already been consistently scoring A1 for physics). They supported their request by explaining that they wanted more time to revise for their other subjects, which was a reasonable request since students could already 'skip' remedial classes (usually conducted during ACT) for subjects that they excel in. Ms Er encouraged both Xian and Chan to keep an open mind and try out the intervention before making a final decision. She told them that if they still wanted to opt out of the intervention after trying it, they would be allowed to do so. When Ms Er informed me of the possibility of Xian and Chan dropping out of the study, I was concerned as it would impact my research study from both a methodological as well as theoretical perspective. From a methodological perspective, it would make comparing class-based average physics test scores across the years difficult. From a theoretical perspective, the students' zone of proximal development would have been negatively impacted given the absence of these 'peer coaches', who were popular in class since they shared their physics knowledge with the other students. I had discussed this issue with my supervisor (Neil Mercer) and collectively we agreed that such was the nature of real-world research and we would address the additional methodological/theoretical issues should the need arise. Silently, I was hopeful that they would find the intervention interesting and helpful, and hence would choose to continue with the intervention. Fortunately, after they participated in the first CMCPs-PT cycle, they decided to continue with the intervention. Xian had disclosed in a reflection exercise (see section 6.4) the reason for his decision to continue with the intervention:

Although it was optional for me to go for this prescriptive tutoring, I chose to go for it as I thought it would benefit me a lot more than the normal physics lessons did. This was because I could expose my physics knowledge and concepts to my fellow classmates and teachers in a much clearer and easier manner, thus they could brought up my misconceptions/misunderstandings, so that I could correct them

and remember the right concepts. Also prescriptive tutoring helped me see my fellow classmates' various means of solving any particular questions which might be different from mine. Therefore prescriptive tutoring is beneficial to me (Xian, 22 Apr 2009; reproduced verbatim).

Given the workload needed for implementation of the intervention, Ms Er and I decided that for the first term, I would conduct the CMCPs sessions, prepare the PT 'notes', and conduct the PT lessons. Initially, she would observe what I did (including analysing the protocol data) and over time, my scaffolds would fade such that by the end of the year, she would be conducting the entire intervention by herself.

6.3 Procedure and Time-line

The substantive portion of the main study was carried out from 8 Jan to 18 September 2009, with the students taking the bulk of their GCE 'O' level examinations in October and November 2009 (practicals and mother tongue language examinations were conducted in June). There were a total of 23 students in 4E1 who took pure physics, and despite the teachers' (Ms Er and Mr Ng) initial suggestion for three students (Gabo, Dino, and Zhan) to drop the subject in the academic year 2009, no student did. This was presumably due to their increased interest in the subject, as well as their belief that they would do well for the subject (see section 6.4).

Figure 6.1 summaries the key events of the main study. In total, 12 CMCPs-PT cycles were conducted, covering various concepts from 16 topics: Pressure, Kinetic Model of Matter, Transfer of Thermal Energy, Temperature, Thermal Properties of Matter, General Wave Properties, Light, Electromagnetic Spectrum, Sound, Static Electricity, Current of Electricity, D.C. Circuits, Magnetism, Electromagnetism, and Electromagnetic Induction. There was at least one CMCPs-PT cycle conducted every month of the academic year leading up to the GCE 'O' levels in October, except for May and June when the students were busy preparing for and taking their 'O' level mother tongue language papers, as well as their Chemistry and Physics 'O' level practical examinations, and September when the students were taking their

preliminary examinations.

20 Oct 08 – Survey 1	2 Apr 09 – CMCP5 6 Apr 09 – PT5	24 Jul 09 – CMCP10 29 Jul 09 – PT10
8 Jan 09 – CMCP1 9 Jan 09 – PT1	16 Apr 09 – CMCP6 20 Apr 09 – PT6	5 Aug – Survey 4
29 Jan 09 – CMCP2 30 Jan 09 – PT2	17 Apr 09 – CMCP7 21 Apr 09 – PT7	5 Aug 09 – CMCP11 12 Aug 09 – PT11
12 Feb 09 – Survey 2	22 Apr – Survey 3 / Reflection 1	12 Aug 09 – CMCP12 20 Aug 09 – PT12
12 Feb 09 – CMCP3 16 Feb 09 – PT3	8 Jul 09 – CMCP8 13 Jul 09 – PT8	24 Aug 09 – Students' Reflection 2
22 Feb 09 – Teacher early-Reflection	14 Jul 09 – CMCP9 20 Jul 09 - PT9	18 Sep 09 – EOY Prelims
12 Mar 09 – CMCP4 13 Mar 09 – PT4		5 Oct – Teacher Final Reflection

Figure 6.1: Schedule of key events for the main study

6.4 Data Collection, Analysis, and Findings

Like the pilot study, both quantitative and qualitative data were collected for this main study. Three short survey questions regarding their perceptions of group-work were posed and collected after every CMCP sessions. Also, four student surveys, two student reflection pieces, and two teacher reflection pieces were collected in addition to test score data. Additionally, video recordings for the first hour of every PT session were made.

6.4.1 Evaluation of Students' Learning Outcomes

While results from the pilot study suggests that the intervention was effective in helping students improve their understanding of physics concepts, resulting in improved test scores, I wanted to know whether similar effects could be experienced in a whole-class setting. However, I was unable to replicate my initial control/alternate/intervention groups with a pre/post test methodology due to logistical and resource constraints. I had the resources to

only work with one school for this research study, and because Bartley had only one class of students at the secondary four level taking pure physics, I had no control group to work with. In addition, it was not feasible for me to approach another school to have them offer me a class of students who would serve as a control group because I would have nothing of value to offer them in return (especially since those students would be taking their GCE 'O' level examinations at the end of the year as well). Hence, in order to have some form of meaningful comparison in order to ascertain whether the intervention had indeed been effective, I obtained historical test score records from the school. In particular, I obtained the *actual* GCE 'O' level physics scores for the past six years (from 2003-2008), as well as the cohorts' *expected* physics scores. The *expected* score is directly derived from the students' PSLE scores (see Chapter Four), and the Singapore Ministry of Education uses this score (known as the expected mean subject grade, or expected MSG) to evaluate whether a school had 'value-added' to a student's academic performance (see Ng, 2007, for a discussion on how the Singapore Ministry of Education assures educational quality in Singapore public schools). Broadly, a student's MSG is calculated based on the numerical grade (as compared to the absolute score) that student obtained for his/her respective subject. Distinction grades are A1 and A2, pass grades are B3, B4, C5, and C6, while fail grades are D7, E8 and F9. Hence, if student Alpha obtained a B3 for physics, his physics MSG is 3, while if student Beta obtained a C4 for physics, then his physics MSG is 4. Combined, their average MSG for physics would be 3.5.

Based on discussions with my supervisor (Neil Mercer) and advisor (Christine Howe), we collectively decided that comparing the GCE 'O' level results of the 2009 cohort against an averaged MSG of several previous cohorts would be more equitable than comparing it against specific years' results. Also, to provide another basis for comparison, I obtained the students' GCE 'O' level chemistry scores, since students who took physics also took chemistry, and being a natural science subject involving abstract concepts, chemistry is somewhat similar in nature to physics. Biology scores were not considered because it was only recently offered in the school. It is noteworthy that the classroom configurations have remained very similar during

the past years; only students in the 4E1 class of each cohort took pure chemistry and physics. Hence, I am comparing similar groups of students in the 4E1 cohort across the years.

For the 2009 GCE 'O' level examinations, every student had passed their physics examination. It is noteworthy that even the three students who were ear-marked at the end of secondary three to drop physics due to their consistent failure had passed the subject – Gabo had scored a B3, while both Dino and Zhan had scored a C5. No student scored below a C5, while the mode grade was a B3. Expectedly, both Xian and Chan scored A1s, while five other students also scored distinction grades. The break-down of their results is provided in Table 6.1.

Table 6.1: Summary of the students' 2009 GCE 'O' level physics grades

GCE 'O' level Physics Grade	Number of Students
A1 (distinction grade)	3
A2 (distinction grade)	4
B3 (pass grade)	12
B4 (pass grade)	1
C5 (pass grade)	3
C6 (pass grade)	0
D7 (fail grade)	0
E8 (fail grade)	0
F9 (fail grade)	0

Table 6.2 provides a summary of the comparison of physics (and chemistry) test scores. Looking specifically at the data for physics, it is worthwhile noticing that the students' 6-year and 3-year average physics scores are similar at 3.75 and 3.8 respectively. Comparing the 2009 cohort's 'O' level average MSG with the 6-year and 3-year average MSG reveal that the 2009 cohort outperformed these two averages by almost one entire grade point (2.87 as compared to 3.75 and 3.8). Additionally, the 2009 cohort did much better than was expected of them, given that the cohort was expected to obtain an average MSG of 4.2 when they had achieved an average MSG of 2.87 instead. In other words, it may be considered that the intervention *value-added* to students' performance by almost one and one-half grade points (from 4.2 to 2.87).

I wanted to obtain another means of comparison and, hence, included the students' chemistry scores in Table 6.2. The MSG for chemistry also improved significantly for the 2009 cohort – from about 4.03 and 4.06 for the 6-year and 3-year average MSG respectively to 3.29 for the 2009 cohort. On the surface, this data could be indicating that the 2009 cohort did exceptionally well in general, and a claim could be made that the 2009 cohort's improved physics scores is not an indication that the intervention was effective. In order to evaluate this claim, it is necessary to ascertain whether physics 'outperformed' chemistry on a comparative basis. To perform such a comparison, I calculated the *difference in chemistry and physics actual MSG* for the 'O' level examinations. I found that the 6-year and 3-year average MSG difference were similar, at 0.28 and 0.25 respectively (in favour of physics). However, for the 2009 cohort, the difference in average MSG for the 'O' level examinations between chemistry and physics is 0.42 in favour of physics. Given that the difference in MSG between chemistry and physics had actually increased in favour of physics for the 2009 cohort, the result suggests that the intervention did play a role in the 2009 cohort's physics test scores.

Table 6.2: Comparison of MSG results

	Physics		Chemistry	
	Expected MSG	'O' level MSG	Expected MSG	'O' level MSG
2009	4.20	2.87	4.20	3.29
3-year average [2006-2008, inclusive]	4.20	3.8	4.20	4.05
6-year average [2003-2008, inclusive]	4.03	3.75	4.03	4.03

In short, based on an analysis of the available quantitative data consisting of historical test scores from a standardised international examination, the evidence suggests that immersion in the intervention contributed to improved students' learning outcomes, leading to an improvement by almost one and one-half grade points as indicated by their average actual

GCE 'O' level MSG compared with their expected average MSG, or almost one grade point as indicated by their average GCE 'O' level MSG compared with either the historical six-year or three-year average MSG. It is also important to note that every cohort included in the comparison with the 2009 batch had students who dropped physics on their teacher's recommendations at the end of secondary three. However, this was not the case for the 2009 cohort.

6.4.2 Teacher's Initial Reflection of Involvement in the Intervention

Throughout the main study, I obtained Ms Er's reflection on her involvement in the intervention twice. The first occasion was early on in the year (in Feb 2009), after we had conducted two CMCPs-PT cycles. I had asked Ms Er for her impressions on the intervention thus far, and she said that she would reflect on the intervention (and her involvement in it), and provide me with a written response. She asked if I needed her to address any issues specifically, or if there was a 'word count' I would require. As I wanted to know what was important to her *from her perspective*, I responded that I had no specific requirement, and that my only request was that she provided me with something that was frank and thought through. Given her busy schedule (in addition to teaching/administrating in school, she was also enrolled for a Master degree program at the Singapore National Institute of Education), she took about two weeks to provide me with her written reflection. By this time, we had already completed the third CMCPs-PT cycle.

Her written response consists of five paragraphs, and is 393 words long. I shall produce her reflection piece verbatim, and provide a discussion of her reflection on a paragraph-by-paragraph basis. The first paragraph from her reflection piece is provided below:

The Prescriptive Tutoring project has been very useful in helping me to identify specific misconceptions and learning difficulties that my students face in the learning of physics. Benson has been very helpful in facilitating the process, with sincere commitment to sustain this project in the long run at Bartley. He has been

very generous with his time to guide the students in their learning journey and support us teachers in implementing this project, be it the selection of contextual rich questions, the skill of reviewing chat logs or the sharing of insights he gathered about the students. (Ms Er, 22 Feb 09, paragraph 1).

In her first sentence, she identified that the intervention *helped her to identify specific misconceptions and learning difficulties* that her students faced in the learning of physics. For example, Figure 6.2 provides protocol data taken from the second CMCPs session, which was used in its corresponding PT session. In brief, while attempting to solve a question on basic wave properties, Rarty referred to the textbook and found the general wave formula ($v = f \lambda$). He also found (on page 214 of the textbook) a section stating that as sea water rushes to shore, its' speed decreases. Hence, Googi (Chan's nickname for this session) concluded that "v decreases". Rarty then asked "what is v...volume or speed[?]", which indicated that he was not sure what the variables in the (basic) formula ' $v = f \lambda$ ' represented. When Ms Er and I were talking about this particular discourse snippet prior to the PT session, I mentioned that I found it really hilarious that Rarty would think that the 'v' in ' $v = f \lambda$ ' could represent "volume". She replied that she "wanted to cry in frustration" when she saw that particular comment, and was surprised that Rarty would think that 'v' could represent "volume".

Question 2

■ Water waves in the sea move from a deeper region to a shallow region. State the change, if any, in the frequency, wavelength, period, and speed of the waves by filling in the blanks below with either "increases", "unchanged", or "decreases". [2]

Frequency: [] Wavelength: [] Speed: [] Period: []


[Rarty] pg 214
 [Rarty] info is there
 [Googi] so v decreases
 [Rarty] ya
 [Rarty] wait
 [Rarty] what is v
 [Rarty] volume or speed  *Not listening in class?*

Figure 6.2: PT slide taken from PT session 2

Figure 6.3 provides another PT slide taken from the second PT session. Students Bobo (Mumo's nickname for that session) and Lopi were attempting the same question (Question 2), and Mumo had referred to the text book (specifically to page 214), where he also read that as sea water rushes to shore, its speed decreases. However, he was unable to explain why its speed decreases, and neither could Lopi. Ms Er and I agreed that students should not merely memorise the fact that as sea water rushes to shore, its speed decreases (or more generally, when a wave enters a shallower region, it's speed decreases). Hence, I explained in class that it is because of the friction between the water and the sand at/near the shoreline that causes the speed of the sea water to decrease as it reaches the shore (see Figure 6.4).

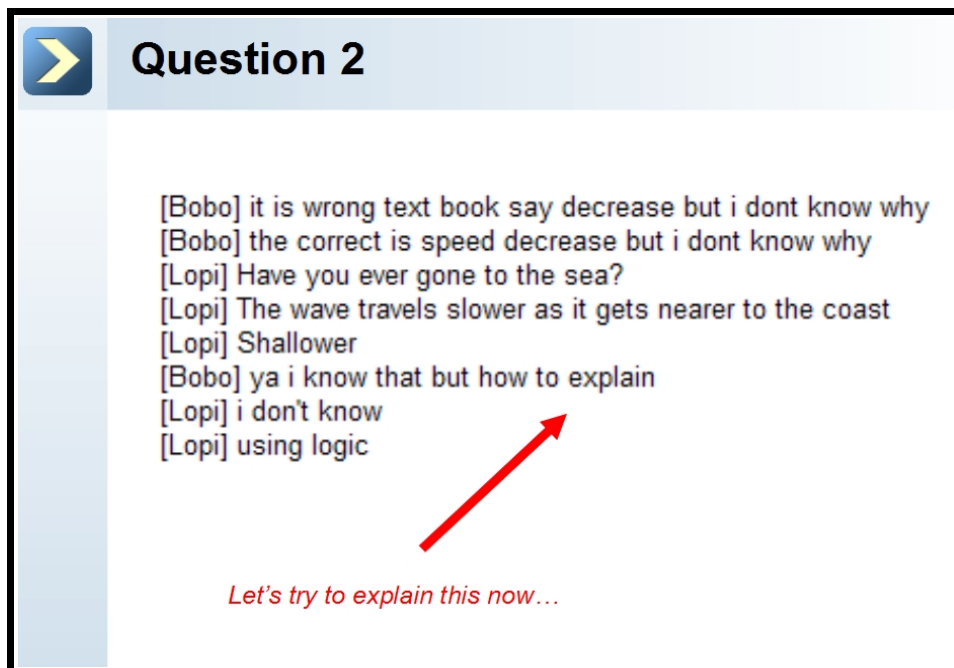


Figure 6.3: Another PT slide taken from PT session 2



Figure 6.4: Benson explaining question 2 in class

After my explanation, the students remained somewhat silent. At this moment, Ms Er contributed to the explanation (see Figure 6.5; she was off camera and on the right, so the students turned their heads to look at her) and told the students that “another thing you can think of is, if the speed keep increasing as it goes to the shore, it will never stop – it will just

keep moving. It must slow down then it can U-turn, just like free fall. If you throw a ball up, if the speed does not decrease it will keep going up. Until the speed [dramatically decrease and slow down so that it can return?] (students laughing). So the speed must slow down then can return, just like the water must return.”



Figure 6.5: Ms Er contributing to the explanation of question 2 (off camera on the right)

I believe it was such instances that made Ms Er reflect that the intervention was very useful in helping her to identify specific misconceptions and learning difficulties that her students face in the learning of physics.

The second and third sentences (of her first paragraph) reflects her acknowledgement that I was fully committed to the project, and spent time selecting the questions to be posed for the CMCPs sessions, reviewing the chat logs with her, sharing with her my opinions on how to address students' misconceptions, and even creating the first three PT 'notes' and conducting the PT sessions. I had conducted the first two PT sessions while she observed and contributed from the sidelines, and we co-conducted the third PT session together. Throughout this time, I took care not to behave and act like the information gathered (e.g. students' misconceptions)

and created (e.g. PT 'notes') were exclusively mine, and I believe she appreciated and reciprocated by being actively involved in the intervention and sharing her views with me liberally. Beneath the surface, I believe she was trying to indicate that the intervention required a lot of time and effort to conduct, and on her own, she would be unable to conduct the intervention (as per how I was doing it) on her own. We had spoken about the effort needed to source for appropriate questions, set up the computer laboratory, print out the discussion logs, review and analyse the logs, and finally produce some form of documentation that was helpful during the PT sessions. At present, teachers are not required to do any of these activities, and even the sourcing of questions (for traditional revision lessons) is made simple by the existence of pre-prepared 'Ten-Year-Series' (TYS) worksheets or test and examination papers from other schools. I told her that while I think context-rich questions are more thought provoking and could yield interesting student insights, we did get deep student insights from the 'regular' questions we posed as well. Additionally, I suggested that the more technical/administrative tasks, such as the setting up of the computer laboratory and the printing of discussion logs, could be handled by the school's IT assistant (Mr Das). She said that if she needed his help on a regular basis, then she would need his reporting officer (the Head of Department for IT) to give his permission. Alternatively, she said she could consider a work-around using her own staff (e.g. asking a more IT-savvy experimental laboratory assistant to perform this task), but was concerned that the lab assistant's job scope does not include computer-related duties. Sensing that she might be facing certain constraints, I offered to continue performing such technical/administrative tasks until a suitable solution as to who would provide such technical/administrative support could be found.

The second paragraph from her reflection piece is provided below:

I noticed an increased motivation in this group of Physics students who had participated in this project. I attribute this to the deeper understanding they are able to attain in the various concepts via this project. This "deeper understanding" came about because students are "forced" to verbalize their logical thinking both to

their peer and teacher. The collaborative nature of the computer laboratory sessions also encouraged them to learn from one another and “talk” about Physics in a non-threatening environment. Previously, the interaction was mainly between the teacher and student via homework exercises and during lessons. (Ms Er, 22 Feb 09, paragraph 2).

Ms Er had perceived an *increase in motivation of the physics students* and attributes this to a *deeper understanding* they had attained in various physics concepts as a result of the intervention. In my surveys, I did not ask the students about how motivated they were to study physics, but I did ask them during the initial conducted on 20 Oct 08 and second survey conducted on 12 Feb 09 how much they liked learning physics (Figure 6.6 illustrates how this question was posed). All 23 students answered both surveys, and the average score for the initial survey is 2.17, while the average score for the second survey is 1.96. Hence, the survey data supports Ms Er's perception of increased motivation (see also section 6.4.4).

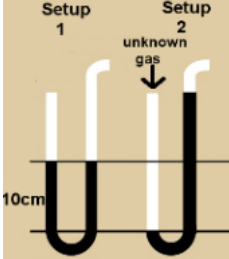
I _____ learning Physics
(1) very much like (2) like (3) have no special liking or disliking for (4) dislike (5) very dislike

Figure 6.6: Survey question to ascertain how much students like learning physics

In the third and fourth sentences, Ms Er revealed her perception that because the CMCPs sessions *force students to verbalise their thinking processes to each other* (and hence also the teacher), they come to a deeper understanding of the physics concepts being discussed. Additionally, she recognises that the collaborative nature of the CMCPs sessions *encourages students to learn from one another and talk about physics in a non-threatening environment*. Table 6.3 provides an illustration of such a “talk about physics in a non-threatening environment”. As can be seen from the discussion snippet provided in Table 6.3, Dino had “forgot” about the concepts in the topic, pressure. However, Wagi did not chide Dino and instead engaged Dino in problem-solving as an equal by seeking her opinion (e.g. “listen to my explanation whether it sounds logical”). Eventually, both students collaboratively obtained a

valid answer to the problem, with Dino expressing joy at the end of the problem-solving endeavour.

Table 6.3: Illustration of talk about physics in a non-threatening environment

Question Posed	Discussion Snippet
<p>John and Cindy filled a manometer with an unknown liquid of density $50,000\text{kg/m}^3$ as shown in Setup 1. They then introduced an unknown gas into the manometer as shown in Setup 2. John calculated the pressure of the unknown gas to be $50,000\text{ Pa}$, while Cindy says it is $100,000\text{ Pa}$. Who (if any) is correct? (Assume atmospheric pressure is $100,000\text{Pa}$)</p> <p>[2]</p>	<p>Dino: i forgot le</p> <p><i>[Here, Dino states that she has forgotten, presumably about the topic.]</i></p> <p>Dino: u ?</p> <p>Wagi: tinkng ...</p> <p>Wagi: i tink both wrong..</p> <p><i>[Notice that Wagi did not chide Dino for forgetting, and instead stated that she thinks that both John and Cindy were wrong. She is indeed correct, but has not yet offered reasons for her answer.]</i></p> <p>Dino: wait ah</p> <p>Dino: i think first</p> <p>Dino: is density the pressure of a liquid?</p> <p>Dino: or is it onli for mercury?</p> <p><i>[Here, we see evidence that Dino had indeed forgotten about what she has learnt for this topic. She equates density with pressure, which is incorrect.]</i></p> <p>Dino: eh</p> <p>Dino: nono</p> <p>Dino: i sae wrong alrd</p> <p><i>[Dino meant that "i sa[y] wrong alr[ea]d[y]", which implies that she recognised that density and pressure are not equivalent]</i></p> <p>Wagi: listen to my explanation whether it sounds logical</p> <p><i>[Wagi has an explanation, but is not sure if it is "logical" and hence asks Dino for her opinion. Notice that Wagi still asks for Dino's opinion despite the fact that Dino had shown that she had forgotten much about the topic.]</i></p> <p>Dino: ok</p> <p>Wagi: in this situation the pressure of unknown gas shld be more than of</p>
	

	<p>atm pressure..</p> <p><i>[Wagi is saying that in the situation depicted at Setup 2, the pressure of the unknown gas should be more than the atmospheric pressure. She is indeed correct, and provides further explanation in her next statement.]</i></p> <p>Dino: ya</p> <p>Wagi: therefore the pa on the liquid is atm pa with liqiud pa</p> <p><i>[While's Wagi's explanation is not precise, her answer is broadly correct. A more precise explanation would be to say that the pressure on the liquid just beneath the unknown gas is the sum of the atmospheric pressure plus the liquid pressure caused by the difference in height of the liquid columns.]</i></p> <p>Dino: and the pressure on set up 1 should be equal to the atmospheric pressure right</p> <p><i>[Following Wagi's line of reasoning, Dino contributes to the thought process and asks if the pressure at the surface level of the liquid must be equal to atmospheric pressure for Setup 1...]</i></p> <p>Wagi: yes</p> <p>Dino: so both not correct</p> <p><i>[...and upon confirmation from Wagi, concludes correctly that both John and Cindy were incorrect, since their calculated values was no higher than atmospheric pressure]</i></p> <p>Dino: :D</p> <p><i>[Dino draws a 'happy smiling face' to express her joy at contributing to the answer]</i></p>
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Ms Er acknowledged in her final sentence (of the second paragraph) that *traditionally, interaction between her and her students had been via homework exercises* (when she marks their solutions to the questions posed) *and during lesson time* (when they ask questions, or give answers to her questions). Presumably, she is implying that the CMCPs sessions extend the interaction she has with her students.

The third paragraph from her reflection piece is provided below:

The tutoring session conducted after the computer laboratory session was a focused and purposeful remediation where the common mistakes/misconceptions, as well as answering techniques were addressed using examples from the students' chat log. This provided a realistic background to the kinds of potential mistakes they can make during assessment. (Ms Er, 22 Feb 09, paragraph 3).

In her third paragraph, she stated that she found the PT sessions to be *focused and purposeful not only for addressing mistakes and misconceptions, but they also address students' answering techniques*. For example, Figure 6.7 depicts a slide used in the first PT session. When asked to explain if (and why) John would feel the same amount of pain regardless of whether it was a boy on a bicycle (40kg) or a man on a motorcycle (120kg) rolling over his legs, Zouk provided an instinctive, 'everyday' answer instead of a more appropriate, 'scientific' one (see Mortimer & Scott, 2003, p. 13, for a discussion on the social language of science). Initially when we were discussing possibilities for why Zouk could have provided such an answer, we thought that it was because her 'concept awareness' was weak. While I believe that Zouk's awareness of the appropriate concepts to use when solving that particular physics question was weak, I also believe that her provision of an 'everyday' answer was a direct response to the 'everyday' nature of how that question was posed. Said differently, students often try to provide 'scientific answers' if the questions posed are 'scientifically phrased', and provide instinctive 'everyday answers' if the questions posed are phrased in a natural, social, and/or non-scientific prose. Sub-section 6.5.2.2 provides a further discussion on this matter.

In the final sentence of her third paragraph, I believe the word "realistic" was used to highlight the actual mistakes that students make, as opposed to the ones inferred by, say, a teacher when marking answer scripts.

Question 1

- Joe was lying straight on the floor when a boy on a bicycle (total mass = 40kg) rolled over his legs. This was immediately followed by a man on a motorcycle (total mass = 120kg). Fortunately, Joe is fine, and said that the pain caused by the bicycle is the same as the pain caused by the motorcycle. Is this possible? Explain your answer. [3]

Zouk _	its possible because
Zouk _	motorcycle at higher speed

Veve _	Q1 is because the time is different
Ertty _	aaa...what??
Ertty _	where do u get the time from??
Veve _	the bicycle must hv a longer time to pass by

Reveals a lack of problem-solving strategy. Where is your physics principles or formula to back up your answer?

Figure 6.7: Slide showing Veve's 'unscientific' answer

The fourth paragraph from her reflection piece is provided below:

Reviewing the chat logs also provided me with deeper insights about the learning progress and difficulties faced by my students. I am delighted to find significant improvement (in terms of conceptual reasoning) in some of my students, who were struggling last year. It is obvious that the collaborative learning environment (which provided a useful learning alternative) and the immediate focused remediation after the laboratory sessions played an important role in helping these students to clarify their doubts. The chat logs also pointed out the learning gaps that my students face which enabled me to tackle it quickly in the classroom lessons during revision. (Ms Er, 22 Feb 09, paragraph 4).

In this paragraph, Ms Er essentially acknowledged that *reviewing the students' discussion logs provided her with deeper insights about her students' learning progress as well as the difficulties they face in understanding the topic.* For example, when we were discussing insights gleaned from the third CMCPs session, she told me that when teaching the topic

pressure, the term "vacuum" is often mentioned in passing as it was expected that students understand what a "vacuum" means and implies. However, the students' discourse during the third CMCPs session shows clearly that they do not understand what actually a "vacuum" is (see Figures 6.8 and 6.9). As a result of this insight that she has gained, she mentioned to me that she would spend some time to ensure that students in her future classes understand this basic term before she actually teaches about the various concepts of pressure.

>

Question 2

■ In a simple mercury barometer shown on the right, the length of the vacuum column is 24cm, while the length of the mercury column is 76cm. What will happen to the length of the vacuum column if the glass tube is pushed deeper into the mercury pool? [1]

- (a) The length of the vacuum column will increase
- (b) The length of the vacuum column will decrease
- (c) The length of the vacuum column will stay the same
- (d) Not enough information to answer the question

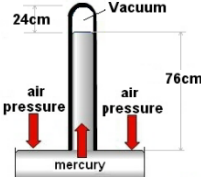


Figure 6.8: Question posed during the third CMCPs involving the term "vacuum"

Question 2

Abba _	when u push it downwards
Abba _	th water in th beaker will spill out
Abba _	while th vacuum th same
Abba _	isn it?

Qe qe _	the formula is
Qe qe _	$P = 1 / V$
Qe qe _	so when pressure increases
Qe qe _	if glass tube is pushed deeper into the mercury pool, the length of the mercury column will decrease.
Qe qe _	as pressure increases, volume has to be lesser

*Misconception over what is vacuum and what is gas pressure...
Vacuum means "nothing" – there is no volume to a vacuum!
Vacuum is just "empty space"!*

Figure 6.9: Students' discourse revealing their lack of knowledge of the term "vacuum"

Ms Er reported that she found *significant improvements in terms of conceptual reasoning* in some students who were struggling last year. Earlier in our discussions, she had mentioned specifically that she saw improvements in Mumo's and Gabo's conceptual reasoning skills. While it is tempting to suggest that such improvements may be seen after only three CMCPs-PT cycles, Mumo and Gabo had taken part in the pilot study. Hence, they had in total undergone six cycles of the intervention. Since "[m]ost learning does not happen suddenly: we do not one moment fail to understand something and the next moment grasp it entirely" (Barnes, 1992, p. 123.), some amount of time is needed for students to understand and appreciate the objectives of the intervention so as to benefit from it. Naturally, while the time required will vary for different students, Ms Er was able to see the improvements in Mumo and Gabo (and possibly other students) by February 2009. To Ms Er, it is "obvious that the collaborative learning environment" (i.e. the CMCPs sessions) and the "immediate focused remediation" (i.e. the PT sessions) thereafter "played an important role in helping these students to clarify their doubts". Her observation that the intervention helps students to clarify their doubts has been reported by the students themselves as well (see sub-section 6.4.4.1).

The fifth (and final) paragraph from her reflection piece is provided below:

I find that this project complements and supports what I am currently teaching in the classroom. Specifically, misconceptions were arrested and addressed earlier, preventing a snowballing effect. I am happy to be involved in this project and I look forward to more sessions with my students. (Ms Er, 22 Feb 09, paragraph 5).

As a revision intervention, Ms Er recognises that the intervention *complements and supports her teaching activities in the classroom*, in the sense that “misconceptions were arrested and addressed earlier”. She concluded the reflection piece by stating that she “look forward to more sessions with [her] students”. In my opinion, her willingness to go forward with the intervention (whereby she would play a much greater role in the intervention) lends weight to what she has provided me in this reflection piece, and is essentially an acknowledgement of the positive outcomes she sees in the intervention.

6.4.3 Teacher's Final Reflection of Involvement in the Intervention

In early September 2009, after the conduct of our final CMCPs-PT cycle, I asked Ms Er to provide me with her final reflection of her involvement in the intervention. I had asked if she could address three specific main themes in her reflection (see Appendix 6.1) and she did provide me with answers to those questions (see Appendix 6.2). However, she surprised me with a narrative paper (on 5th October 2009), which she had written and submitted just recently as part of her MEd course-work on Professional Development (PD) and Professional Learning (PL). Entitled “PD & PL Narrative Paper: Inquiring Into My Professional Development and Learning Trajectory through Narratives”, the 3,165 word-count paper contains her personal narrative of her involvement in the intervention. She had sent it to me purely because she thought I might be interested to read her narrative, since it focused exclusively on the activities and events pertaining to the intervention. It is this narrative that I have chosen to be included in this dissertation for discussion. In my opinion, this personal narrative is her reflection in which she talks about matters that *were significant to her*, and in this sense, it

provides a much more authentic account of her final reflection on the intervention.

Broken down into six distinct sections, she starts her narrative by first describing her first meeting with me in 2008 (this section was entitled "The meeting on 2nd Semester, Year 2008"). She expressed that my presentation to her and the Principal on the proposed intervention "sounds good...No harm to give it a try to see what happens". She emphasised that after I had presented the positive results of the pilot study, what got her more interested in the intervention "was when Benson further presented selected snapshots of students' chat-logs of the misconceptions that surfaced and how they were addressed." In other words, the 'hook' that got her interested in the intervention was when I showed her the students' misconceptions, many of which neither Mr Ng nor she had knowledge existed in their students' minds.

In her second section, entitled "The tension and struggle", she explains,

I taught Physics for five year and have been through a powerful initiation into the culture of using assessment as the ends-means tool...I had become more pragmatic. The goal of a good O level results has closed the doors to several creative teaching and learning strategies that is deemed as taking too much time....a "Drill and Practice" (D&P) approach is put in place to ensure sufficient repetition of core and popular concepts being tested. D&P focus on rigor and places an importance in the practice of past year Cambridge papers for the basic standard and other school papers for an improvement in the Physics standards in my students.

She had initially thought that the D&P approach was effective in helping students gain conceptual understanding, and "[w]ith good results that validated my teaching approach for the past two years, I have continued and even intensified in the D&P rigor". However, she "started to have nagging doubts about the effects of such intensive D&P on my students'

achievement and cognitive development beyond the O levels. Some students who have graduated returned and lamented how they are not able to cope at the next level of education." She also reflected on her position as the Head of Department for Science, and "felt upset that my core duty as a teacher has been neglected." She recognises that "most of my students have experienced failure in the educational system at PSLE (with low PSLE score)" and decided to "[f]orget about creative teaching methods where students seemed to learn better and are excited; but this does not translate into good academic results. I made the decision to use assessment as the driving force in my teaching and only infused selected 'creative' learner-centered strategies in some of my lessons."

In her third section, entitled "Prescriptive Tutoring with Benson", she stated her decision to continue with the intervention "for another year with the same group of students and measure their improvement through the O level results". She had been "bought in by the theories that validated this PT approach, the positive findings in the pilot student and the amount of misconceptions that had been surfaced". She was, however, concerned that due to the intervention, a longer time is now "required to complete the revision of each topic using the PT revision approach as compared to the traditional D&P revision approach. This could compromise on the time that is left for D&P." However, she went ahead with the intervention because "the benefits and the validation from research studies gave me the conviction to move ahead". She had quoted a passage from one of my papers (Soong, 2008b) as an example of research studies "that supported the PT approach":

At the wider social level, it is the learners' interactions with instructors and other learners that "give them perspective, place them within a community of learning, and contribute to their mastery of concepts and skills" (Price & Petre, 1997, p. 1041). Such social interactions are vital in nurturing the spirit of learning, since "the individual ...becomes familiar with its methods and subject matters, acquires needed skill, and is saturated with its emotional spirit" (Dewey, 1916, p. 26). The concepts and skills exposed at the social level would then later be internalised

(Vygotsky, 1978), leading to individual improvements. (Soong, 2008b, p. 595-6)

She then talked about how the intervention started, and how I initiated her “into the language of Prescriptive Tutoring” – in short, I “led the first few sessions”, initiated her “into the process of how to conduct the lab sessions”, shared with her “the misconceptions as identified from the chat-logs”, highlighted “how students are thinking and their learning difficulties”. I also “addressed all these in the classroom sessions” where she “took on an observer role to learn how” I approached “these learning difficulties and how [I] connected with the students by discussing physics ideas from students’ mental model”. She also saw how I “corrected students’ misconceptions and brought students to adopt the normative view”.

She described that as we progressed, I had “relinquished the lead and began to play the supporting role in this programme.” I had taught her “how to analyze the chat-logs, how to better categorize findings and consolidate this information into a useful format that would guide us conducting the classroom sessions” and together, “we discussed about students’ misconceptions, students’ thinking; the whys and the hows and the what’s next? Together we analyzed the chat-logs, conducted the classroom sessions and evaluated how successfully these sessions were conducted and how it could be better.” She said I was “a pillar of support, was a mentor, a friend and had this unwavering conviction that affected [her] as well. We believe we are doing something very important and worthwhile and most importantly, we shared common goals and the belief that our students will attain high levels of achievement through this intervention.” Slowly, she was leading the intervention sessions and I “supported where necessary, facilitated [her] learning progress and looked into the menial stuff (e.g the preparation of the computer labs) and at times even prepared the teaching materials for the classroom sessions. This allowed [her] to fully immerse in the core job of reading chat-logs, analyzing my students’ thoughts and thinking about how to teach”.

In her fourth section, entitled “My thoughts on PT”, she reiterated her earlier reflection that the intervention “has been very useful in helping me to identify specific misconceptions and

learning difficulties that my students face in the learning of physics". She reported an increase in student motivation and attributed this directly to the intervention. She was delighted to find "significant improvement (in terms of conceptual reasoning) in some of my students who were struggling last year. It is obvious that the collaborative learning environment (which provided a useful learning alternative) and the immediate focused remediation after the laboratory sessions played an important role in helping these students to clarify their doubts" and, in her opinion, "being involved in this project is a meaningful, enlightening, if not a transformative experience/process".

In her fifth section, entitled "What I have learnt", she recalls her "training as a teacher at NIE [National Institute of Education; the only teacher training college in Singapore] on the teaching of Physics". She had "been taught the typical elements of good classroom teaching – knowing students prior knowledge, use of 'hooks' to get students attention, building new concepts via the linking to previous knowledge, proper sequencing, assessment to further inform revision, etc." and "have used various strategies to understand students' preconceptions/misconceptions to better inform my teaching practice. These included marking homework, professional discourse with fellow colleagues, reading the markers' report and relevant materials/books, or classroom discussions to glean insights into what and how students think". However, despite all these activities, "the amount of knowledge gleaned (mostly generic in nature) in my five years of teaching experience is much less than the insights that I gained through one year of PT". She explained that:

Not only was I empowered with this new knowledge, reading students' chat-logs has further enabled me to better connect with my students' learning needs (cognitive needs especially). It has fostered a collegial and positive learning climate where there is a greater and richer exchange of knowledge and concepts between me and my students. I noticed a greater confidence level in many students and the enthusiasm and perseverance to arrive at the correct answer "using sound physics concepts/ideas"....

PT has allowed for a "thinking" culture to evolve, an important skill that will help prepare my students for the demands of education at the next level. Watching how my students are propelled to the next level (=depth) of learning, the interest generated in Physics, as well as witnessing this intellectual growth in my students; it has further increased my satisfaction and fulfillment as a teacher. All these are beyond the academic aspects which I had focused on previously.

She reflected that during the intervention, she "made changes in [her] teaching and also started to re-think about [her] knowledge of Physics, re-examined [her] fundamental beliefs about [her] students and the goals of education. In the process, [she] was made vulnerable and forced to take risks". She said that she "was lucky" to have me as "an external support figure" who provided her with "access to subject-matter expertise and given [her] time to be comfortable with the role of a learner".

In the final paragraph of the fifth section, she feels "a sense of pride" as she "see the keen interest and confidence [her] students now have in this subject that [she is] teaching". As a result of the intervention, "there wasn't a chance to conduct the intensive D&P in the ten weeks before their Preliminary Examinations". Despite of this, she is "proud of their results and achievements" (the students had done well for their Preliminary Examinations) as she "finally saw how [her] students were able to make sound use of Physics concepts to answer the questions, something that occurred because they understood and not because they have been drilled to recognize and remember". However, "[n]o matter what the academic outcome it will be", she feels "a sense of achieve and pride in the journey" as she is "able to connect with them...able to respond effectively to their learning needs, being able to teach from their mental model and most importantly...[her] students being able to finally understand and apply the concepts of the subject" that she taught.

In her concluding section, entitled "Looking forward", she recognises that "pedagogy and

theory are not separate but are both generative in producing knowledge” and acknowledges that she “still have much to learn on how to bring theory and experience into dialogue”. She concludes on a hopeful note, stating that she is sure the MEd programme she is currently taking will help her bridge this gap (theory and experience) and propel her “forward to another wave of learning”.

In short, the key themes that stood out for Ms Er are (i) the intervention helped her to “identify specific misconceptions and learning difficulties” that her students faced in the learning of physics. In fact, she found that “the amount of knowledge gleaned (mostly generic in nature) in [her] five years of teaching experience is much less tha[n] the insights that [she] gained through one year of PT”. (ii) Students who had undergone the intervention had an “increased motivation” to learn physics due to the “deeper understanding they are able to attain” as they were forced to articulate their thought processes to both their peers and their teacher. As a result, she can “see the keen interest and confidence [her] students now have in this subject”. (iii) The intervention provided a “non-threatening environment” where students can learn from one another and “‘talk’ about physics”, thereby fostering “a collegial and positive learning climate where there is a greater and richer exchange of knowledge and concepts between [her] and [her] students”. (iv) The prescriptive tutoring sessions were “focused and purposeful”, as she “saw how [her] students were able to make sound use of Physics concepts to answer the questions, something that occurred because they understood and not because they have been drilled to recognize and remember”. (v) The intervention “complements and supports” her current classroom practices, “preventing a snowballing effect” of misconceptions. In sum, she found that “being involved in this project is a meaningful, enlightening, if not a transformative experience/process”.

6.4.4 Students' Reflection of Involvement in the Intervention

6.4.4.1 Perception of Difference between Intervention and Previous Revision Methods

During the two student-reflection exercises, the students were asked for their written feedback on what they thought were the differences between the intervention and previous revision

methods. In order to more fully explore the students' views, somewhat similar questions regarding their perception of difference in revision methods were asked twice – once in April 2009 and the other in August 2009. Some of the questions asked in the first feedback session were more skewed towards individual revision practices while the questions asked in the second feedback session were more skewed towards revision practices as a class. Taken holistically, responses to both these question types may provide us with insights into how the intervention had influenced the students' revision practices within and outside of their classroom. Also, asking these somewhat similar questions twice over a period of time has a distinct advantage – a shift or change in students' perceptions over a time period may serve as an indication for further analysis. If the main themes remain similar, then there is a good chance that the students were not merely telling me what they thought I wanted to hear, especially since they had no access to their earlier feedback.

The questions posed for the April 2009 feedback collection exercise that was used as a means of obtaining student feedback on revision practices are provided in Figure 6.10, while the question posed on revision practices for the August 2009 feedback collection exercise is provided in Figure 6.11. For both these sessions, sheets of paper asking students to pen their reflections on their involvement in the intervention were given out opportunistically as the students unexpectedly had at least one free period that day (because a teacher was absent on medical leave) while I was in school. Out of a total of 23 students, 16 students completed both reflection exercises; 20 students completed the first feedback, while 18 students completed the second. Absenteeism was the only reason why some students did not complete the feedback. While all the students' reflections were reviewed, due to space constraints, only the feedback of students who completed both the reflection exercises are provided in Table 6.4. In addition, by placing the students' comments for the two reflection exercises side-by-side in a table-format, we may see if the students' comments are similar for both sessions (mostly they are).

Theme 1: Let's start with your experience in this learning environment.

- In your opinion, do you think there is a difference between how you were revising Physics in the past, and now? If so, in what ways?
- Clearly there is a change in how the classroom lessons in school are conducted. But what about your own, self-directed study (e.g. own revision at home). Are you doing anything difference now? Are you spending more, less, or the same amount of time revision for Physics?
- What is your impression about the way the class format has changed? In which areas is it good? Or Bad?

Figure 6.10: Questions posed on revision practices during the first students' reflection exercise

1) I would like you to reflect on how physics revision in the past was being done (during Secondary 3) as compared to how we are doing it now. In your opinion, are there any differences in the revision methods? (e.g. is there more discussions with the teachers and with fellow students? Do you think more deeply about physics concepts?)

Figure 6.11: Questions posed on revision practices during the second students' reflection exercise

Table 6.4 provides a tabulated view of the 16 students' perceptions of differences in revision practices between the intervention and previous revision methods. From an individual perspective, seven students reported that they were attempting more physics questions as part of their revision practice. This was surprising to me, as neither Ms Er nor I had intentionally given students additional physics questions to practice on. Hence, they were using their own resources in order to work on those additional practice questions. In addition, I felt that since the intervention focused on helping students *understand* physics concepts better, an improved understanding on the students' part should actually allow them to attempt *fewer* physics questions. A deeper analysis of why students were attempting more physics problems as part of their individual revision practice indicates that they spend more time attempting physics problems largely because their *interest* in physics had increased, and/or they attempt more problems in order to help them *understand physics concepts better*. For example, Abalon explained that "I used to read textbook, read the worked examples. But now, I start doing all the questions in the ten years series, and other school papers...I am beginning to like physics now, hence, I will spend more time to do physics at home", while Chalice

Table 6.4: Students' perception of difference between intervention and previous revision methods

Student	Reflection 1 Comment Snippet	Reflection 1 Themes	Reflection 2 Themes	Reflection 2 Comment Snippet
Taki	Yes, there is a difference. I used to read textbook and do questions from TYS but now whenever I encounter some physics questions I don't know, I will consult my teacher and ask until I understand. I am spending more time for physics now. The class format is better now as more misconceptions are cleared.	<p><i>Seek help</i></p> <p><i>Clearing of misconceptions</i></p> <p>More time spent on physics</p>	<p>More discussions</p> <p>Exposure to different types of questions</p> <p>Think more deeply</p> <p>Understanding/application</p> <p><i>Seek help</i></p> <p><i>Clearing of misconceptions</i></p>	Yes, I think that there are more discussions with the teachers and with fellow students and in this way, students will get to expose more different type of questions. Previously, when I am doing physics questions and encounter questions that I don't know, I will just write any sensible answer. But now, I think more deeply about physics concepts and will apply it to the questions, even to questions I am not sure. Now, I will also seek help from the teachers if I have any question so that this can clear my misconception.
Abalon	I used to read textbook, read the worked examples. But now, I start doing all the questions in the ten years series, and other school papers. I will also clarify my doubts with my teachers and private tutor. More time. I am beginning to like physics now, hence, I will spend more time to do physics at home. In the past... I think read textbook will help me correct my misconceptions. But now, I learn how to study smart. Seek teachers help to clarify my doubts.	<p>Trying more questions</p> <p><i>Seek help</i></p> <p>More time spent on physics</p>	<p>Understanding/application</p> <p><i>Seek help</i></p> <p>Identification of weaknesses</p>	<p>Yes, in my opinion, I think that there is a difference in the revision methods. Last time, whenever I made a misconception in any topic, I would just memorise the concepts and not trying to understand it. But now, when I make a misconception, I would seek help from Miss Er and Mr Benson to understand the concepts and use it for answering questions.</p> <p>I think prescriptive tutoring is very useful. Especially when our teachers (Ms Er & Mr Benson) are willing to view our chat logs and point out our misconceptions. :D</p>
Buddy	Yes, I try the TYS Qs and try to make everything logical and not just memorise everything. I go through prescriptive tutoring (notes). I try my best not to do last-minute study and	<p>Trying more questions</p> <p>Understanding/application</p> <p>More time spent on physics</p>	<p>Think more deeply</p> <p>More discussions</p>	We definitely think more deeply about physics concept than last year and there is more discussions with teacher and even more among the students mainly our closer friends. Revision methods are better now

	I forgot how much time I used to spend for physics. I practice more.			but I feel that when we do papers, the questions we are not sure of should be taught slower. Prescriptive tutoring is very helpful.
Wagi	At first, I just browse through textbook, memorising facts and formulas – the content. But I know its important to know how to apply the skills by doing a lot of qns. To be honest, I feel that I am spending less time than before. It is good. When going thru mistakes, many good questions are raised and answered efficiently – open discussion. Sometimes that lead to confusion but all rest of the time it is doing good. I thought physics was just – maths – purely applying formulas. But than now I know, misunderstandings should be cleared as soon as possible as it leads to getting the whole qns wrong, even the concept.	Trying more questions <i>Understanding/application</i> <i>More discussions</i> Clearing of misconceptions Less time spent on physics	<i>More discussions</i> <i>Understanding/application</i> Think more deeply	In Sec 3, we were flooded with Bartley and other school papers, do it and mark it. If we have questions, we revise them. Now, I am able to identify appropriate concepts to be applied. There are more discussions as a class and sometimes we try to find a way to explain our answer which may not be correct. And in the end if it is wrong, we know where we went wrong when teacher or friends ask, 'how you know?'. I am force to think deeply to figure out a way for correct answer without being contradicted.
Coca	Not much difference in methods used to revise physics concept (reading textbook to memorise facts, applying them into questions from assessment books/TYS). Same amount of time spent on revision on certain areas which is still unclear on. Lesser time spent on topics which are understood with misconceptions cleared after prescriptive tutoring. Class format is good.	None specified Less time spent on physics	More discussions	There are differences in the revision methods. More discussions with teachers and students over questions and concepts.
Ziki	Of course there is a difference. I will have more points of misconceptions that I have to take note of during revision. Doing more practice questions. More time	<i>More discussions</i> <i>Clearing of misconceptions</i> Trying more questions	Understanding/application <i>More discussions</i> <i>Clearing of misconceptions</i>	In the past, I memorised the concepts. But now, I understand the concept before I memorise the formulae of the concept. Of course, we discuss with our teachers on

	for revision for physics. Can be able to know my mistakes and correct my friend's mistakes, win-win situation :)	More time spent on physics		how we understand the concept by answering the questions set by teachers. From there, we think on how the concepts link each other and clarify our doubts on how we think of the concepts.
Yoyo	I think there is a difference. In the past, I did question alone, I stopped when I was not able to solve the problem. But now, I discuss with friends, exchange ideas which can help me a lot. I spend 2 or 3 hours to study physics during the weekend. I think this learning intervention helps me to strength my physics concept and let me know exactly where my misconceptions are...it teaches me how to solve the questions by using a correct physics method.	<p><i>More discussions</i></p> <p><i>Understanding/application</i></p> <p>Clearing of misconceptions</p> <p>Problem-solving strategy</p> <p>More time spent on physics (inferred)</p>	<p><i>More discussions</i></p> <p>Understanding/application</p>	During Secondary 3, the discussions with teachers and classmates were less compared to we are doing it now. Before we only went through the test papers and did however [sic] on time, we did not know how to use physics concepts to answer the questions properly and apply to our daily life.
Xian	<p>There is slightly difference in my methods of revising physics between past and now. Nowadays, I would like to ask some of my classmates some physics questions, and share with them each other's way of solving. At the same time, I still revise the textbook for better understanding of concepts.</p> <p>Actually, I think i'm doing the same thing for revising physics most of the time, but the amount of time I spent for revision is getting longer and longer.</p> <p>The change in the format will definitely help the weaker student, in a larger scale, the whole class of 4E1 physics student all will benefit from it...By the helps given by the teacher, I will be able to correct my</p>	<p><i>More discussions</i></p> <p>Clearing of misconceptions</p> <p>More time spent on physics</p>	<p><i>More discussions</i></p> <p>Think more deeply</p>	During Sec 3, revision mostly was done by my own, seldom discussion between me and my classmate. Certainly, in Sec 4, I have been involved in active discussions during classes, after classes and even after school. Having discussions with teachers more frequently, I'm able to think more deeply about physics concept, this helps me remember concepts much vividly.

	misconception efficiently.			
Lopi	<p>Yes, I do my revisions by reading less textbook but try to understand the main concept of that particular chapters.</p> <p>I find myself think and answer in a more systematic way. I am spending less amount of time revision for physics. I prefer the new way of the class format than the previous one. It is definitely a good change.</p> <p>I used to think that how much misconceptions we can have but later I am surprised that I have numerous misconceptions which I never know I have.</p>	<p><i>Understanding/application</i></p> <p><i>Uncovering/clearing of misconceptions</i></p> <p>More systematic in thinking</p> <p>Less time spent on physics revision</p>	<p><i>Understanding/application</i></p> <p>More discussions</p> <p><i>Clearing of misconceptions</i></p>	<p>Yes, there is definitely a different.</p> <p>In secondary 3, I depended heavily on textbooks and memorising without really understanding the concepts and hence did not know how to apply. With prescriptive tutoring, I have more opportunities to discuss with my friends and uncover our physic misconceptions.</p>
Chalice	<p>Yes, I think there is a difference in the way I revise physics. In the past I usually spent most of my time remembering the answer and TB more than practise question. Now I practise more and try to understand the concept instead of memorising them.</p> <p>I spent more amount of time for physics revision. 2-5 Qns a day (not MCQ; structure Qns).</p> <p>Physics lesson is more interesting to me now than before.</p> <p>Good Areas:</p> <p>Student know their misconception, clear them with good and funny example to help them have a clear concept.</p> <p>Teacher get to know student misconception : </p>	<p>Understanding/application</p> <p>Trying more questions</p> <p><i>Clearing of misconceptions</i></p> <p>More time spent on physics revision</p>	<p>More discussions</p> <p><i>Clearing of misconceptions/doubts</i></p>	<p>Yes, there is differences in the revision methods.</p> <p>In secondary 3, we usually depends on textbook and practice the question as a revision. Now, there are more discussion about questions in class which can help and clarify doubts and more opportunities for students to share their thoughts.</p>
Cullen	<p>Yes. In the past, when there were tests or exams. I would just re-read the textbook</p>	<p>Trying more questions</p> <p>Seek help/ask questions</p>	<p>More discussions</p> <p>Clearing of doubts/misconceptions</p>	<p>In the past, revisions were done through drawing mind-map and simply listen to Ms</p>

	<p>over and over. But now I start practicing questions and clear my doubts by asking questions.</p> <p>Yes. I've spent slightly more time to revise for physics.</p> <p>Seems like everyone has a great improve on physics</p>	<p>More time spent on physics</p>		<p>Er to explain some selected questions for us. There were very little discussion in the class.</p> <p>Now, we can clear most of our doubts by discussing in class and I think teachers get to know our weaknesses.</p>
Rarty	<p>Yes, I asked my brother to give me tuition as well.</p> <p>I am spending more time on revising physics</p> <p>Good: Prescriptive tutoring more misconceptions are being understood and cleared</p>	<p><i>Clearing of misconceptions</i></p> <p>More time spent on physics</p>	<p>More discussions</p> <p><i>Clearing of misconceptions</i></p> <p>Understanding/application</p>	<p>There is more discussions now than in sec 3 and we will get to know the possible misconceptions when answering physics questions and not repeat them. We also discussed with each other to understand how to answer questions properly in physics concept more than in sec 3.</p>
Sarsi	<p>No difference, just that I pay much more attention in class, I do not really revise physics compared to other subjects...</p> <p>The lessons in classroom are much more detailed and precise now...Impression?</p> <p>Good obviously, benefited me (class) by a lot. In the area which made us think out of the box, and go into the very little detail of every topic taught. It also made us or cultivate us to ask more and think more, compared to the past.</p> <p>I can't see any flaws as I am enjoy every lesson.</p>	<p>Paying more attention in class</p> <p><i>Think more deeply</i></p> <p>No difference in time spent on physics</p>	<p><i>Paying more attention in class</i></p> <p><i>Think more deeply</i></p>	<p>First of all, I do not study physics, but I pay super attentive in class. I am doing normally as what I do for physics this year, but the difference is, I become more sensitive to questions nowadays as in I think a lot deeper than just looking the question on its surface. One very common way of me doing my revision is by talking, discussing and debating out all our misconceptions.</p>
Zouk	<p>Yes. It has been more lively and absolutely interesting where I am able to share knowledge with others and get to know my weak areas as well as get corrected by the teachers. Yes. I tend to spend some empty times to look through worksheets given by the school and have a challenging moment</p>	<p><i>More discussions</i></p> <p>Trying more questions</p> <p>More time spent on physics</p>	<p>Identification of weaknesses/Clearing of misconceptions</p> <p><i>More discussions</i></p>	<p>Yes, there is more opportunities given to each individuals to know their weaknesses and got enlightened through class discussion with teacher.</p>

	doing it....now I realised the importance of spotting our all the misconceptions in order for myself to improve.			
Gabo	Yes. Tend to solve the question to the best of my ability until an answer is shown. More time.	Work harder on problem-solving More time spent on physics	More discussions Identification of weaknesses/Clearing of misconceptions Understanding/application Think more deeply	There are more discussions with the teachers and students to help identify key points or common mistakes which students or the teachers may sometimes make. With this happening, we help to correct one another and avoid making the same mistake over and over again. Physics concepts are important to think about and understand how they are derived so that we can use it without hesitation.
Maria	A lot differences, because in the past when I do Qn I never ask myself what the physics concept, but now I constantly asking myself what is the physics concept. Yes definitely I'm doing something different at home. I do revision in the assessment book (Longman) I spend more time revision. Better I guess in the way that we work more with our classmates to solve the physic Qn and the teacher going through the logs and pointing out the mistake.	<i>Understanding/application</i> <i>More discussion/working together</i> Clearing of mistakes/misconceptions More time spent on physics	Exposure to different types of questions More discussion <i>Understanding/application</i>	Yes, now I tend to expose to more difficult Qn and lots of discussion. Broaden the way I think to ans the physic Qn. Each Qn have to apply a physic concept. In the past we are not expose to difficult Qn and we did not apply physic concept, we tend to apply random ans. Not much discussion.

related that "Yes, I think there is a difference in the way I revise physics. In the past I usually spent most of my time remembering the answer and TB [textbook] more than practise question. Now I practise more and try to understand the concept instead of memorising them".

Six students indicated that as part of their individual revision practices, they now have discussions with other students. For example, Yoyo stated that "In the past, I did question alone, I stopped when I was not able to solve the problem. But now, I discuss with friends, exchange ideas which can help me a lot", while Zouk explained that "It has been more lively and absolutely interesting where I am able to share knowledge with others and get to know my weak areas as well as get corrected by the teachers."

Four students indicated that they now focus on getting a better understanding of physics concepts, as opposed to the past whereby they memorised formulas and answers. For instance, Maria explained that "in the past when I do Qn I never ask myself what the physics concept, but now I constantly asking myself what is the physics concept", while Buddy stated that he would "try the TYS Qs [ten-year series questions] and try to make everything logical and not just memorise everything".

Three students indicated that they now sought help and asked questions. For example, Taki explained that "I used to read textbook and do questions from TYS [ten-year-series] but now whenever I encounter some physics questions I don't know, I will consult my teacher and ask until I understand", while Cullen stated that "In the past, when there were tests or exams. I would just re-read the textbook over and over. But now I start practicing questions and clear my doubts by asking questions."

Other changes to individual physics revision practices reported by the students are (i) thinking in a more systematic way, (ii) paying more attention in class, (iii) thinking more deeply, and (iv) working harder on problem-solving. On the whole, 12 students indicated that as a result

of the intervention, they spent more time on physics revision. Three students indicated that they spent less time, while one student reported that he spent the same amount of time (as in the past). Out of the three students who spent less time on physics revision, only Coca provided an explain. He spent less time for physics revision now because he spends the "same amount of time...on revision on certain areas which is still unclear on...[while spending] [l]esser time...on topics which are understood with misconceptions cleared after prescriptive tutoring".

As members of a class-based community, it was the students' perception that the biggest difference between the intervention and previous revision methods lay in the amount of discussion the class has as a whole. After all, 14 students indicated that the intervention resulted in "more discussions" both between teacher and students, as well as between the students themselves. For instance, Lopi explained that "In secondary 3, I depended heavily on textbooks and memorising without really understanding the concepts and hence did not know how to apply. With prescriptive tutoring, I have more opportunities to discuss with my friends and uncover our physic misconceptions". Her account is corroborated by Chalice, who recounts that "In secondary 3, we usually depends on textbook and practice the question as a revision. Now, there are more discussion about questions in class which can help and clarify doubts and more opportunities for students to share their thoughts". Six students had brought up the theme of "more discussions" during the April 2009 feedback session, which was a session more focused on individual physics revision practices. This indicates that students recognised the benefits of discourse from both an individual as well as class-community perspective.

The students attributed a range of benefits due to the increase of in-class discussions. For example, nine students indicated that they now help each other in understanding and/or applying physics concepts. For example, Rarty explained that "We also discussed with each other to understand how to answer questions properly in physics concept more than in sec 3", while Wagi stated that "There are more discussions as a class and sometimes we try to find a way to explain our answer which may not be correct. And in the end if it is wrong, we know

where we went wrong when teacher or friends ask, 'how you know?'. Six students related that they now thought more deeply about physics concepts. For instance, Sarsi reported that "I become more sensitive to questions nowadays as in I think a lot deeper than just looking the question on its surface", and his account is similar to that of Xian's, who wrote that "Certainly, in Sec 4, I have been involved in active discussions during classes, after classes and even after school. Having discussions with teachers more frequently, I'm able to think more deeply about physics concept, this helps me remember concepts much vividly". Also, nine students reported that the increase in discussions helped them deal with their misconceptions/misunderstandings. For example, Gabo wrote that "There are more discussions with the teachers and students to help identify key points or common mistakes which students or the teachers may sometimes make. With this happening, we help to correct one another and avoid making the same mistake over and over again", and his account is similar to the comment given by Zouk, who stated that "Yes, there is more opportunities given to each individuals to know their weaknesses and got enlightened through class discussion with teacher". Seven students had brought up the theme of "clearing misconceptions" during the April 2009 feedback session, which was a session more focused on individual physics revision practices. This suggests that students had become more sensitive to their own misconceptions/misunderstandings from both an individual as well as a class-community perspective.

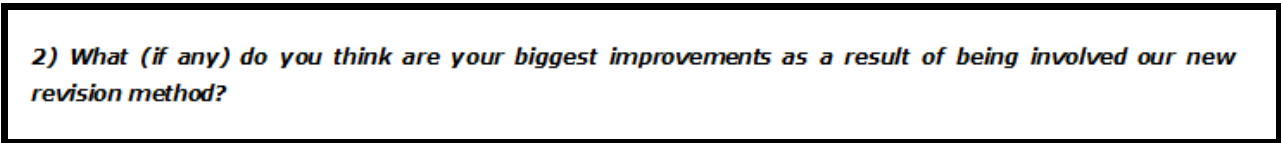
Other changes to the classroom-based revision practices reported by the students were (i) paying more attention in class, (ii) seeking help from the teacher, and (iii) an increased exposure to different types of questions.

Interestingly, out of the three students who were ear-marked to drop physics at the end of secondary three, Dino was absent from school during both the reflection exercises, while Zhan was absent during the second reflection exercise. Gabo (who was also ear-marked to drop at the end of secondary three), was present during both the reflection exercise sessions. While I did not collect attendance data, on the whole, I did notice that Dino and Zhan had a higher

than normal absentee rate from school. Gabo had scored a B3 for his GCE 'O' level physics examination, while both Dino and Zhan scored C5, suggesting that attending the school-based revision intervention had been helpful for achieving a higher score.

6.4.4.2 Students' Perception of Improvements Attributable to the Intervention

During the second reflection exercise, the students were asked to reflect upon what, in their opinion, their biggest improvement as a result of being involved in the intervention. Figure 6.12 provides an illustration of how this question was posed.



2) What (if any) do you think are your biggest improvements as a result of being involved our new revision method?

Figure 6.12: Question posed to students on their biggest improvements as a result of being involved in the intervention

It was the opinion of all but one student (Rarty's response was "No comments") that the intervention helped improve their physics. Interestingly, Rarty was the only student who was not ear-marked to drop physics at the end of secondary three to score a C5 for his GCE 'O' level physics examination.

The themes that emerged from an analysis of students' reflections on their biggest improvements are:

- *Understanding of concepts (and application to problems):* 14 students identified that their biggest improvements lay in their improved understanding of physics concepts and/or their improved abilities in applying relevant physics concepts to the questions posed. For instance, Wagi explained that "Even if it is a small part of the chapter, I am able to explain the full theory of how something happens and apply it e.g. pressure in a bottle on a hot day, heat chapter, movement of electrons and many =)" [=) is the depiction of a smiley face] and Abalon reported that "Instead of memorising concepts

and applying on questions, I am now understanding the concepts and apply it to any questions”.

- *Clearing of misconceptions:* Four students stated that their improvement in physics was a result of their misconceptions being corrected. For example, Taki reported that “The biggest improvement as a result of being involved our new revision method is where our misconceptions are cleared” while even Chan (one of the top two physics students in the class) acknowledged that “I correct some of my misconceptions with the help of the new revision method”.
- *Knowing where their weaknesses lay:* Three students expressed that their improvements in physics was a result of themselves knowing where their weaknesses in physics lay. For instance, Zouk wrote that she improved as she now had an “understanding [of] my mistakes in a scientific way thus enabling me to improvement myself” while Taki explained that “our misconceptions are being pointed out and teacher corrected it. In this way, students can learn from their mistakes and will not make it again”.
- *Identifying of topics:* Two students reported that their physics had improved as a result of their ability “to identify the topic being asked” in the questions posed.
- *Thinking in a more systematic way:* Lopi stated that she now thinks “in a more systematic way which will help me in constructing my answers”.
- *Tackling questions which they could not before:* Gabo stated that he can now “tackle questions which I could not before and I think I have improved as compared to the year before”.

In short, according to the students, it is their opinion that their biggest improvements as a result of being involved in the intervention lay in better understanding of physics concepts, and the application of physics concepts to problems posed. The students also identified other improvements such as the clearing of misconceptions and the related factor of knowing where their weaknesses lay. Also, they improved in their identifying of topics for the questions posed, thinking in a more systematic way, and tackling questions which they could not before.

In all, the key themes raised by the students are similar across the two reflection exercises, thereby strengthening the claim that the students were honest in giving their opinions, and not merely telling me something they thought I wanted to hear.

6.4.4.3 Other Students' Perceptions

In order to triangulate the students' written reflections, four surveys were conducted throughout the intervention in addition to the short survey questions posed during the CMCPs sessions (see Figure 6.15). The fourth and final survey (which was summative in nature, and taken by all 23 students) was conducted in August 2009. During this final survey, the students were asked to rate on a Likert scale how helpful they thought the intervention had been in their revision of physics. Also, they were asked how much they thought prescriptive tutoring would benefit their juniors who were in secondary three. Figure 6.13 depicts key questions posed to the students during the final survey.

On the whole, I think that prescriptive tutoring has been _____ in my revision of physics concepts.
(1) very helpful (2) helpful (3) neither helpful nor unhelpful (4) unhelpful (5) very unhelpful
REASON:

On the whole, I am _____ with the prescriptive tutoring environment.
(1) very comfortable (2) comfortable (3) neither comfortable nor uncomfortable (4) uncomfortable (5) very uncomfortable
REASON:

I think that prescriptive tutoring will _____ my juniors (e.g. those in Secondary 3).
(1) greatly benefit (2) benefit (3) neither benefit nor dis-benefit (4) dis-benefit (5) greatly dis-benefit
REASON:

Figure 6.13: Key questions posed to the students during the final survey

With an average score of 1.3 (out of 5), all the students thought that the intervention was either very helpful or helpful in their revision of physics concepts. As Sarsi explained, "It's

effective in luring the misconception we have out on paper in black and white where it can be corrected". Similarly, all the students thought that the intervention would either greatly benefit or benefit their juniors (a score of 1.4 out of 5). Many students said that they would be envious of their juniors if these juniors were to embark on the intervention. For example, Sunny wrote that "They will have 2 yrs of prescriptive tutoring eh! So lucky" while Wagi stated that "I envy them! They have more help than us! But it will be a definite benefit."

With an average score of 1.5, all the students except Zhan (who provided a score of 3, indicating he was neither comfortable nor uncomfortable with the intervention) were either very comfortable or comfortable with the intervention. Abalon was comfortable with the intervention because she found it to be "[v]ery fun. Especially to try to solve answer/solve questions through online chats", while Xian was very comfortable with the intervention because "I'm able to practice typing. Expressing my thoughts in words/letters allows me to communicate better with others".

In order to track the students' interest in learning physics', I asked students how much they liked learning physics during all the four survey sessions. Initially, their average score for that question was 2.17, and this score steady reduced to a value value of 1.74 as depicted in Figure 6.14. Hence, it is suggestive that the intervention helped students gain an interest in physics, which Ms Er had observed and reported in her reflection pieces. Interestingly, Cullen and Kiki were on medical leave during the tenth CMCPs session. However, they contacted Ms Er and seek permission to come to school in order to attend the CMCPs session, which was held during ACT (after 1.30pm). They informed Ms Er that they were feeling better, and did not want to miss the CMCPs session. After the session, I asked Cullen to Kiki to write on their CMCPs form why they had chosen to attend the CMCPs session despite being on medical leave. Cullen explained that "I attended this session even though I was on MC [medical certificate leave] because I love physics and I want to get A1 for physics!! :D", while Kiki wrote that "I attended the session today even though I was on MC because I feel my physics is not good and the prescriptive tutoring session is helpful in identifying misconceptions". Hence, I

believe the intervention had indeed positively increased students' interest in physics.

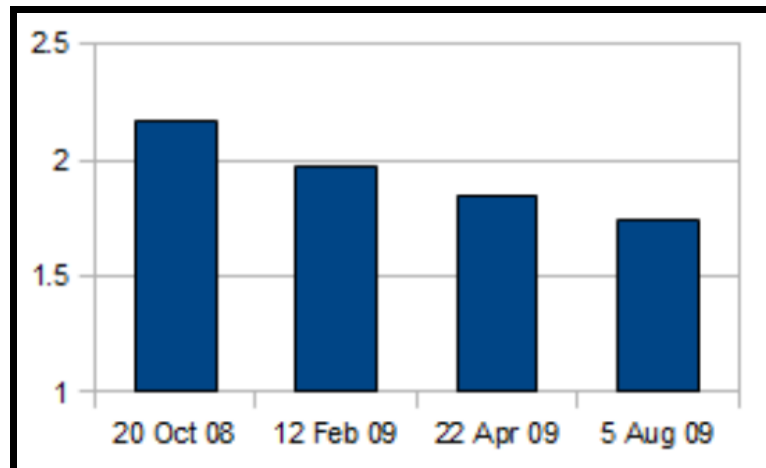


Figure 6.14: Graph showing students increased interest in physics over time

In order to ascertain whether the students thought that group-work helped them with their problem-solving endeavours, they were required to complete three short Likert scale survey questions after every CMCPs session. These short survey questions are depicted in Figure 6.15.

Survey Questions: (to be completed and submitted only after the session)

Q1: Initially, I thought that the questions were:
 Very Easy Easy Neither Easy nor Difficult Difficult Very Difficult

Q2: After trying to answer the questions together with my partner, I found that the questions were:
 Very Easy Easy Neither Easy nor Difficult Difficult Very Difficult

Q3: How do you feel about working with a partner via the computer to solve Physics questions?
 Very Comfortable Comfortable Neutral Uncomfortable Very Uncomfortable

Figure 6.15: Short survey questions posed during the CMCPs sessions

On average across the 12 CMCPs sessions, students initially found the questions to be between “difficult” and “neither easy nor difficult” (scoring an average of 3.27 out of 5). However, after trying to answer the questions together with their partner(s), they found the questions to be between “easy” and “neither easy nor difficult” (scoring an average of 2.79 out of 5). This result indicates that the students found that group-work helped them with their problem-

solving endeavours. In addition, the students generally felt “comfortable” working with a partner via the computer to solve physics problems (scoring an average of 1.94 out of 5). Interestingly, the average for groups with three students were similar for the first two questions (scoring an average of 3.17 and 2.88 respectively). However, the average score of the third question was 2.33. This results indicates that, in general, students in groups of three found working within their groups more difficult than the groups with two students. These results are summarised in Table 6.5.

Table 6.5: Summary of results of CMCPs survey questions

	Average scores of all students	Average scores of students who were in groups of three
Q1: Initially, I thought that the questions were [____] 1 (Very Easy) – 5 (Very difficult)	3.27	3.17
Q2: After trying to answer the questions together with my partner, I found that the questions were [____] 1 (Very Easy) – 5 (Very difficult)	2.79	2.88
Q3: How do you feel about working with a partner via the computer to solve physics questions? 1 (Very Comfortable) – 5 (Very uncomfortable)	1.94	2.33

6.4.5 Causes of Students' Difficulties when Solving Physics Problems

While the revision intervention was initially targeted at uncovering students' misconceptions/misunderstandings in order to prescriptively address those issues, I found that while misconceptions/misunderstandings were prevalent in all topics in which the revision intervention was carried out for, I also identified other factors that also significantly (negatively) affected the students' ability to successfully solve the physics questions posed (and therefore obtain a correct solution to the problem). At the start of the research study, I was expecting that misconceptions/misunderstandings would account for the vast majority of difficulties students face when solving physics problems. After all, my own experience teaching physics, together with the existing body of knowledge on students' misconceptions (e.g. Modell et al., 2005, Richardson, 2004) pointed in this direction. However, while reviewing

the students' protocol data in order to perform prescriptive tutoring, I was somewhat surprised to notice that while misconceptions/misunderstandings still accounted for a good portion of students' difficulties during problem solving, other factors were also significant and highly prevalent. As a result, an additional track to the original research work was added in which I sought to map out specific difficulties the students encountered while they were solving physics problems. This sub-section reports on the key findings of this new strand of research.

When reviewing the logs, I made notes regarding students' difficulties during problem-solving. These notes were then compared against the notes made by Ms Er, and the results indicated in this sub-section highlights our joint argument. A fuller discussion, including a brief literature review of students' difficulties when solving physics questions, is provided in section 6.5.2. It is important to note that the categories reported are not mutually exclusive; it is possible for a particular difficulty to be classified in more than one category.

6.4.5.1 Knowledge Gaps

The students may have had difficulties solving the questions that we posed simply because they did not have the necessary basic knowledge about the topic we were assessing. Provided in Table 6.6 is a question that we posed, and the subsequent chat discussion by Yoyo and Ziki shows Yoyo's knowledge gap on the topic, 'pressure'. As can be seen from the discussion log, Ziki had identified (correctly) to Yoyo the topic ("topic. pressure. K???") in which the question was meant to address. When Ziki asked for the formula for pressure, Yoyo replied that "i forgot too", and then asked if " $F=ma$ " was the right formula. Even when Ziki responded that the formula she gave was incorrect, Yoyo still thought that it was correct until further reflection, when she realised that it was incorrect ("oh wrong").

Table 6.6: Illustration of knowledge gap

Question Posed	Discussion Snippet
Joe was lying straight	Ziki: topic
on the floor when a boy	Ziki: pressure
on a bicycle (total mass = 40kg) rolled over his	Ziki: K???

<p>legs. This was immediately followed by a man on a motorcycle (total mass = 120kg). Fortunately, Joe is fine, and said that the pain caused by the bicycle is the same as the pain caused by the motorcycle. Is this possible? Explain your answer. [3]</p>	<p><i>[Here, Ziki is stating that this question is based on the topic, 'pressure']</i></p> <p>Yoyo: qn1</p> <p>Ziki: erm...</p> <p>Ziki: wats the formular???</p> <p>Yoyo: i forget too</p> <p><i>[When asked for the formula for 'pressure', Yoyo replied that she has forgotten it]</i></p> <p>Ziki: i use green colour</p> <p>Yoyo: pink la</p> <p><i>[Ziki is using green on the whiteboard, while Yoyo is using pink]</i></p> <p>Yoyo: $F=ma$</p> <p>Yoyo: right??</p> <p><i>[Here, we see evidence that Yoyo has indeed forgotten the formula for pressure, as she provided the formula for Force instead]</i></p> <p>Ziki: no wat</p> <p>Ziki: is pressure leh</p> <p><i>[While, Ziki cannot remember the formula for pressure, he certainly knows that the formula given by Yoyo is incorrect]</i></p> <p>Yoyo: yup</p> <p><i>[Yoyo is actually saying that the formula she provided ($F=ma$) is for pressure...]</i></p> <p>Yoyo: oh wrong</p> <p><i>[...but upon reflection, she recognised that it is 'wrong']</i></p>
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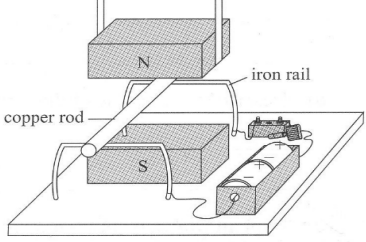
Based on the study, the students had difficulty solving problems in which they lack basic knowledge about. For example, because Yoyo lacked basic knowledge about pressure (including the formula $\text{Pressure} = \text{Force} / \text{Contact Area}$), both Ziki and Yoyo were unable to solve the question until they referred to their textbook in order to obtain the formula.

Throughout the intervention, I noticed that students had knowledge gaps on various topics from when they missed lessons or when there had been miscommunication between teachers. For example, a student may have been absent when a topic was taught in class, or another teacher was supposed to have taught a topic but was unable to do so due to various reasons (e.g. Mr Ng was supposed to have completed teaching the topic on 'pressure' before handing over the class to Ms Er, but he had not completed teaching that topic. However, Ms Er assumed that he had completed teaching the topic). While the conclusion that students would have difficulty solving problems in which they lack basic knowledge about is not revelatory, what is surprising was that the intervention is revision in nature. Hence, the students were meant to at least possess basic knowledge on the topics they were revising on, and their knowledge gaps could be indicative of non-physics based problems, such as absenteeism or lack of coordination between teachers.

6.4.5.2 Concept Gaps

From the logs, I noticed that many students had basic knowledge of various physics concepts, but were unclear of its conceptual meaning or implications. For example, students might know the formula to find a particular physics quantity, but lack the conceptual understanding that would enable them to use that formula to solve a novel problem. Provided in Table 6.7 is a question that we posed, and the subsequent chat discussion by Veve and Sunny shows Sunny's concept gap on Fleming's Left Hand Rule. As can be seen from the discussion log, while Sunny has knowledge of Fleming's Left Hand Rule (i.e. she knows that the thumb represents movement direction, the second finger represents the magnetic field direction, and the third finger represents the current direction), she lacked the conceptual understanding of how to apply this Rule.

Table 6.7: Illustration of concept gap

<p>Question Posed:</p>	<p>4. The diagram shows a copper rod resting on a pair of iron rails. The iron rails are connected to some batteries.</p>  <p>(a) In which direction will the copper roll to when the switch is turned on? (b) Suggest a way to increase the speed at which the copper rod rolls.</p>
<p>Discussion Snippet:</p>	<p>Veve: 4a/ move to the right</p> <p><i>[Veve stated her answer for the first part of the question (4a), which is the correct answer as the copper rod will indeed move to the right, towards the batteries]</i></p> <p>Veve: as the direction of current is outwards</p> <p>Veve: using left hand rule</p> <p>Veve: the force direction is to the right</p> <p><i>[Here, Veve provides the rationale for her answer; she had used Fleming's Left Hand Rule to ascertain the direction of movement of the copper rod]</i></p> <p>Sunny: hey electron flow from negative terminla right</p> <p>Sunny: so current is opposite isit</p> <p>Sunny: right right</p> <p>Veve: yes</p> <p>Veve _ yes</p> <p><i>[Sunny asked Veve if electron flow and the conventional current flow are in opposite directions. Veve replied that they are indeed in opposite direction]</i></p> <p>Sunny: ok i know..</p> <p>Veve: so correct rite?</p> <p>Veve _ 4b?</p> <p><i>[Veve asked Sunny if she thought that the answer to 4a was correct, and if they should move on to the next sub-question, 4b]</i></p> <p>Sunny: i though out if the plane</p> <p>Veve : hah?</p>

Veve: out of the plane?

Veve: Qn4?

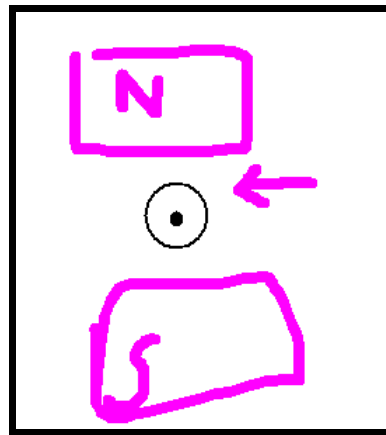
Sunny: yeah

Sunny: a

[Here, Sunny expresses that she thought that the copper rod will move out of the plane]

Sunny: uff..

[To illustrate to Veve how she obtained her answer, Sunny drew a cross-sectional diagram that, in her opinion, demonstrates that the copper rod will move out of the plane. Notice that Sunny has knowledge of Fleming's Left Hand Rule in the sense that she knows what each finger is meant to represent]



Sunny: that one current flow, right?

[This utterance reveals Sunny's concept gap on the Left Hand Rule; she had gotten her answer that the copper rod will move out of the plane because she had thought that the current was flowing to the left, as depicted by her purple arrow pointing to the left. However, while the current is indeed moving to the left on the back iron rail, she should be using the direction of movement of current on the copper rod and not the iron railing]

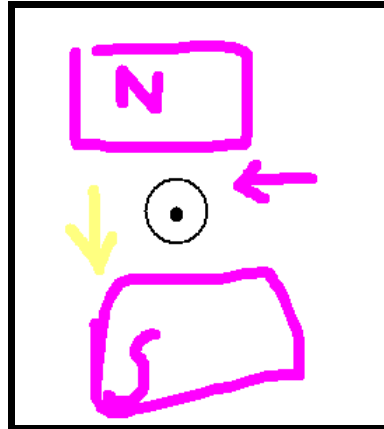
Veve: yah

Veve: the current goes outwards

[Here, Veve is trying to explain to Sunny that the current flow to consider should be that of the copper rod]

Sunny: yellow colour is downwards

[Sunny is illustrating the magnetic field, depicted by a yellow arrow pointing downwards. Here, we see even clearer how Sunny obtained her (incorrect) answer of the copper rod moving out of the plane by the application of Fleming's Left Hand Rule]



Veve: current goes outwards

Veve: rite?

[Veve reiterates her (correct) opinion that the current is moving "outwards" (and not to the left)]

Sunny: to the left what

Sunny: omg idk

[[Sunny reiterated that the current is moving "to the left", but soon acknowledges that she does not know ("omg idk" means "Oh my God, I don't know")]

I observed that the students had difficulties solving problems in which they had concept gaps. For example, because Sunny did not realise that the direction of current to be used in Fleming's Left Hand Rule was that of the current which is flowing within the object in which its movement is to be ascertained, she had difficulty in solving the question posed. In my opinion, such concept gaps exists mainly because students memorise certain rules or formulas without attempting to understand the concepts involved. Hence, for questions on the same topic, these students would get some questions correct, but others incorrect simply due to the features of the questions, rather than the concepts inherent therein.

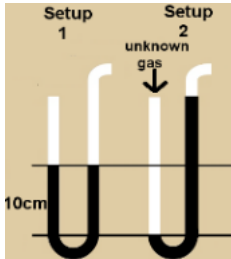
6.4.5.3 Misconceptions/Misunderstandings

While concept gaps and misconceptions/misunderstandings may appear somewhat similar, they differ significantly because of the 'sureness' a student exhibits in his/her conception. For instance, students with concept gaps are, at least in part, aware that they may not fully understand a topic (as in the case of Sunny in sub-section 6.4.5.2 above, where she acknowledged at the end, "omg idk"). In the case of misconceptions/misunderstandings, students actually believe that their conceptions are correct, despite them being misconceived.

For example, Table 6.8 shows a question that was posed to students during the third CMCPs session. Kiki and Xian were collaboratively solving this question when Kiki insisted that his solution, which differs from Xian, is correct. The dialogue snippet provided in Table 6.8 demonstrates Kiki's misconception/misunderstanding with respect to calculating the pressure of a liquid column, and also shows Kiki's lack of understanding of the SI unit for length (a mathematical/logical skills gap). Additionally, I believe the dialogue demonstrates an advantage of anonymity during collaborative problem-solving; Kiki did not know that he was working with Xian (the top scorer for physics), and hence engaged him in conversation as an equal.

Table 6.8: Illustration of misconception/misunderstanding

Question Posed	Discussion Snippet
John and Cindy filled a manometer with an unknown liquid of density 50,000kg/m ³ as shown in Setup 1. They then introduced an unknown gas into the manometer as shown in Setup 2. John calculated the pressure of the	Kiki: using $P = \rho gh$ Kiki: $P = 50000 \times 10 \times 10$ Kiki: $= 5000000\text{Pa}$ Kiki: thats the answer <i>[Using the correct formula for calculating pressure due to a liquid column, Kiki obtained an incorrect answer when he tried to calculate the difference in pressure between the two arms in Setup 2. Notice that he did not convert the height component into SI units, and also his height value is incorrect]</i> Xian:

<p>unknown gas to be 50,000 Pa, while Cindy says it is 100,000 Pa. Who (if any) is correct? (Assume atmospheric pressure is 100,000Pa)</p> <p>[2]</p> 	<p>Xian: height 20cm <i>[Xian indicates to Kiki that Kiki should have used a height value of 20cm instead of 10cm (Xian is correct)]</i></p> <p>Kiki: ya height 20 Kiki: but the gained height is 10 <i>[Here, we see that Kiki is aware that "height [is] 20", but somehow he perceives that it should be "gained height" that matters]</i></p> <p>Xian: liquid experience same P at same level u know? <i>[Here, Xian is pointing out to Kiki that liquid at the same level experience the same pressure]</i></p> <p>Kiki: so whats your working Kiki: the gained height is 10 Kiki: it does not include the actual height what Kiki: so not 20 <i>[Once again, Kiki insists that the height to be used should be "the gained height"...which "does not include the actual height, so not 20"]</i></p>
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The discussion log in Table 6.8 demonstrated Kiki's 'sureness' of his answer. In fact, I conjecture that if another similar problem was given to Kiki, he would have continued to use *gained height* and not *height difference* when calculating the pressure due to a liquid column. I noticed that the students often had difficulties solving questions posed because of such misconceptions/misunderstandings. While some students had unique misconceptions, based on the protocol data collected in this study, it is largely true that if one student exhibits a particular misconception, it is likely that other students would have a similar misconception. For example, analysis of the logs show that there were at least four other students who had this same misconception as Kiki (see Figure 6.16).

Question 1

Abba _	so, Pliquid = $\rho h g$
Abba _	$50 \times 10 \times 10$
Abba _	5000
Abba _	hence, Pliquid is 5000 Pa
Yayi _	$50000 \times 10 \times 10$
Wagi _	pa of gas = $50000 \times 10 \times 10$
Fifa _	$P = 50000 \times 10 \times 10$
Fifa _	= 5000000 Pa
Qwerty _	height 20cm
Fifa _	ya height 20
Fifa _	but the gained height is 10

*Many people used 10cm as the height to find:
Pressure = $\rho h g$
But the **height difference is 20cm** and not 10cm!!!*

*For a manometer, **h is height difference!***

Figure 6.16: Slide taken from the third PT session, showing a common student misconception

6.4.5.4 Mathematical/Logical Reasoning Gaps

I noticed that some students had difficulties solving questions posed because they had weak mathematical/logical reasoning skills. For example, provided in Table 6.9 is a question that we posed, and the subsequent chat discussion by Chalice and Dino shows the latter's weak mathematical/logical reasoning skills; while Dino knows that for a wave, its velocity can be calculated by its frequency multiplied by its wavelength, she states that it is possible for a wave to have its velocity decrease while its frequency and wavelength remain unchanged.

Table 6.9: Illustration of mathematical/logical reasoning gap

Question Posed	Discussion Snippet
Water waves in the sea move from a deeper region to a shallow region. State the change, if any, in the frequency, wavelength, period, and speed of the waves by filling in	<p>Dino: $v = f \lambda$</p> <p>Dino: u noe the sign</p> <p><i>[Notice here that Dino is stating a formula to calculate the velocity of a wave (v), which is frequency (f) multiplied by its wavelength (λ)]</i></p> <p>Chalice: yup</p> <p>Chalice: $v = f \lambda$</p> <p>Chalice: not $f \lambda$</p>

<p>the blanks below with either "increases", "unchanged", or "decreases" [2]</p> <p>Frequency: _____</p> <p>Wavelength: _____</p> <p>Speed: _____</p> <p>Period: _____</p>	<p><i>[We see here that Chalice mistook Dino's lambda sign λ as "divided by lambda"]</i></p> <p>Dino: i trying to make the sign λ</p> <p>Dino: lol</p> <p>Dino: hahah</p> <p>Chalice: kkkk#</p> <p><i>[Dino clarified that she was merely trying to create a lambda sign, and both Dino and Chalice had a good laugh over the miscommunication]</i></p> <p>Chalice: so how???? just use "y" for wavelength. $v = fy$</p> <p>Dino: ok</p> <p>Chalice: ok</p> <p><i>[Both Chalice and Dino agrees to use "y" to represent "wavelength". Hence, the formula would be $v = fy$. Their discourse so far indicates that both Chalice and Dino are aware of the formula]</i></p> <p><i>...[some non-consequential discourse was removed to save space]...</i></p> <p>Dino: my ans</p> <p>Chalice: i am very confuse</p> <p>Chalice: ...</p> <p>Dino: frequency: unchanged wavelength: unchanged speed: decreases period: unchanged</p> <p><i>[Here, we see a weakness in Dino's mathematical/logical reasoning skills. She is aware of the formula $v = fy$, and yet provided an answer which suggests that while frequency and wavelength remain unchanged, speed decreased]</i></p>
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The discussion log in Table 6.9 demonstrated Dino's weak mathematical/logical reasoning skills; if " $v = fy$ ", how can " v " decrease if both " f " and " y " remain constant? I noticed that Gabo had made this mistake as well, and when I checked their secondary three mathematics results, uncovered that they were among the lowest mathematics scorers. It is perhaps for this reason that mathematical abilities are linked to physics problem-solving abilities (see 6.5.2).

6.4.5.5 Not understanding the question

I noticed that students sometimes had difficulty solving the questions posed because they could not understand the question. For example, the discussion snippet provided in Table 6.10 captured Sarsi's difficulty with understanding the question posed.

Table 6.10: Illustration of difficulty in understanding the question posed

Question Posed	Discussion Snippet
<p>Joe was lying straight on the floor when a boy on a bicycle (total mass = 40kg) rolled over his legs. This was immediately followed by a man on a motorcycle (total mass = 120kg). Fortunately, Joe is fine, and said that the pain caused by the bicycle is the same as the pain caused by the motorcycle. Is this possible? Explain your answer. [3]</p>	<p>Sarsi: i dun even understand the question <i>[Sarsi indicated early in the problem-solving attempt that he did not understand the question posed]</i></p> <p>Coca: ... <i>[Students use "..."/> </i></p>

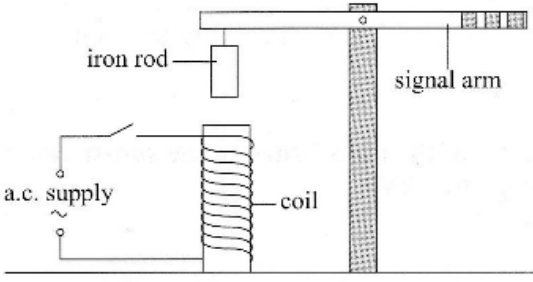
	<p>Sarsi: can i say that joe was ran over 2 times?</p> <p><i>[Here, we see that Sarsi had difficulties understanding the question because the question did not explicitly state that Joe was ran over twice]</i></p> <p>Coca: yes</p>
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I had noticed that students tended to have more difficulties with longer questions. While Sarsi could not understand the question, Coca could. Based on the students' secondary three examinations, Coca had obtain a significantly higher English score (B3) as compared to Sarsi (C5). Hence, like mathematical/logical reasoning gaps, students' difficulty in solving physics problems may be related to their command of the English language, not their understanding of physics.

6.4.5.6 Misreading or Misinterpretation of the Question

The students in the study occasionally did not obtain correct solutions to the questions posed because they misread or misinterpreted the questions. For example, Table 6.11 illustrates a question in which both Taki and Ziki misread. In that question, the students were asked about the movement of the *signal arm*. However, given the presence of the *solenoid* and *iron rod*, the students had to focus their attention on how the *solenoid* would affect the movement of the *iron rod*. As such, some students provided their answers based on the movement of the *iron rod*, and not the *signal arm* (see 6.5.2 for a deeper discussion) and, hence, provided an incorrect answer, as Ziki and Taki had done.

Table 6.11: Illustration of misreading or misinterpretation of the question

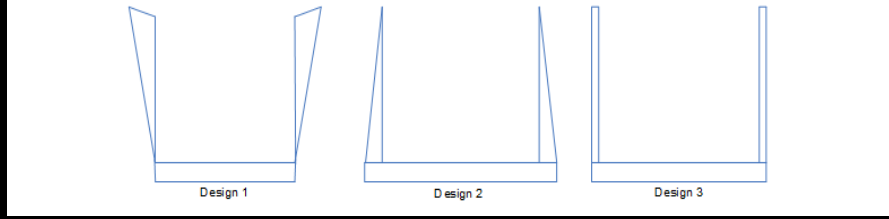
<p>Question Posed:</p>	<p>2. The diagram shows a model railway signal.</p>  <p>What does the signal arm do when the switch is closed? (A) It goes down and stays down. (B) It goes up and stays up. (C) It goes down and then returns to its original position. (D) It goes up and then returns to its original position.</p>
<p>Discussion Snippet:</p>	<p>Ziki: hey</p> <p>Ziki: we r sooo</p> <p>Taki: ?</p> <p>Ziki: stupid</p> <p>Ziki: the ans shld be b</p> <p>Taki: y?</p> <p>Ziki: cuz</p> <p>Ziki: READ Q</p> <p>Ziki: !!!!!</p> <p>Taki: ya</p> <p>Taki: oh ya</p> <p>Taki: is signal arm</p> <p>Taki: not the rod</p> <p>Ziki: YA</p>

Students often attribute such careless mistakes to stress when they make such errors in an examination. While examination stress is very real and may negatively impact a student's performance, we see here that even in a normal, "non-threatening environment", such mistakes are still committed.

6.4.5.7 Weak Concept Awareness

The students in the study sometimes provided solutions to the questions posed based on concepts which are not appropriate for the context in the given question. For example, Table 6.12 illustrates how Rarty obtained a correct answer based on an inappropriate concept. The students were asked which one of the three designs they would choose if the tank was to be used for storing a large amount of mercury. Rarty selected Design 2, which is correct. However, his main rationale for selecting Design 2 was a 'stability' argument, which is inappropriate in the given context. Despite Xian's explanation ("as we noe that the deeper the liquid is the greater the pressure is...so the btm of of the container should be thicker"), Rarty still insists that his answer is valid ("i havent finish explaining...when mercury is filled to the top, the possibility that container falling over is reduced rite? because it is more stable"), to which Xian responded by saying "i think the designer g[o]t consider about that ...".

Table 6.12: Illustration of weak concept awareness

<p>Question Posed:</p>	<p><i>You have been asked to select a design for a tank that is to be used for storing a large amount of mercury. Which design would you choose and why? [2]</i></p> 
<p>Discussion Snippet:</p>	<p>Rarty: the ans is most probably design 2</p> <p>Xian: i think answer is this <i>[Xian drew Design 2 on the whiteboard]</i></p> <p>Rarty: because mercury is a metal, it would be heavy <i>[Here, we see that Rarty is saying that he picked Design 2 possibly due to a 'stability' argument, which is incorrect in the given context]</i></p> <p>Rarty: ya i oso think so <i>[Rarty is agreeing with Xian's answer, which Xian had earlier drew on the whiteboard]</i></p>

	<p>Xian: sorry i dunt think ur answer is right</p> <p>Xian: i mean ur explanation</p> <p>Xian: would u like to listen to mine ?</p> <p><i>[Xian does not agree with Rarty's explanation (the 'stability' argument), and offers his own]</i></p> <p>Rarty: issit the mercury part?</p> <p>Xian: mercury usually is in liquid form</p> <p>Rarty: ya</p> <p>Rarty: but it is still a metal</p> <p>Rarty: but heavier than water</p> <p>Xian: as we noe that the deeper the liquid is the greater the pressure is</p> <p><i>[Xian offers that a 'pressure' argument is more appropriate given the context]</i></p> <p>Rarty: ya</p> <p>Rarty: but design 2 is more stable</p> <p><i>[Once again, Rarty brings up the stability argument]</i></p> <p>Xian: so the btm of of the container should be thicker</p> <p>Rarty: ya</p> <p>Xian: so that can sustain from the great pressure</p> <p><i>[Xian's reason is inline with what the students have been taught]</i></p> <p>Rarty: ur rite</p> <p><i>[Rarty states that he agrees with Xian's reason...]</i></p> <p>Xian: ok settle qn2</p> <p>Xian: lets do 3</p> <p>Rarty: wait</p> <p>Xian: ??</p> <p>Rarty: i havent finish explaining</p> <p>Xian: ok continue</p> <p>Rarty: when mercury is filled to the top, the possibility that container falling over is reduced rite?</p> <p>Rarty: because it is more stable</p>
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	<p><i>[Here, Rarty makes explicit his 'stability' argument. Notice that despite Xian's explanation and Rarty's agreement with Xian's explanation, Rarty still feels strongly that his 'stability' argument is valid as a reason for choosing Design 2]</i></p> <p>Rarty: agree?</p> <p>Xian: i think the designer gt consider about that ...</p>
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I noticed in the discussion logs that whenever students provided seemingly random answers to the questions that we posed, it was because they had not attempted to identify the concepts being assessed by the questions. Sometimes, students fail to identify the relevant conceptual factors in a particular topic being assessed by a question because they lack knowledge about the concepts, as demonstrated in Table 6.13.

Table 6.13: Illustration of knowledge gap leading to seemingly random answers

Question Posed	Discussion Snippet
<p>Joe was lying straight on the floor when a boy on a bicycle (total mass = 40kg) rolled over his legs. This was immediately followed by a man on a motorcycle (total mass = 120kg). Fortunately, Joe is fine, and said that the pain caused by the bicycle is the same as the pain caused by the motorcycle. Is this possible? Explain your answer. [3]</p>	<p>Kiki: pressure question?</p> <p>Zouk: think.so</p> <p><i>[Kiki asks Zouk if she thinks the question is a "pressure question". Zouk thinks so, but is unsure...]</i></p> <p>Zouk: bt.nv.learn.siol</p> <p><i>[...as she has no knowledge of the topic. "bt nv learn siol" means "but never learn sorry"]</i></p> <p>Zouk: wad.u.think.?</p> <p>Kiki: do u rmb anything about pressure?</p> <p>Zouk: errr</p> <p>Zouk: no</p> <p>Kiki: me too --</p> <p>Zouk: ok</p> <p><i>[Here, both Zouk and Kiki acknowledges their lack of knowledge on the topic, pressure]</i></p> <p>Zouk: its.possible.because</p>

	<p>Zouk: motorcycle.at.higher.speed</p> <p><i>[Given the lack of knowledge, Zouk and Kiki were unable to identify the relevant conceptual factors to consider in this question. Hence, Zouk provided a conjecture on why it is possible for the boy to feel the same amount of time – if the motorcycle moved at a faster speed, while the bicycle moved at a slower speed, then the amount of pain would be the same]</i></p> <p>Kiki: higher speed?</p> <p><i>[Kiki questions Zouk's conception of speed...]</i></p> <p>Zouk: nvm.i.anyhow</p> <p><i>[...to which Zouk acknowledged that she randomly provided an answer ("nvm" means "never mind" while "i anyhow" is a colloquial term that means "i did it without thought")]</i></p>
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6.5 Discussion of Findings

6.5.1 Improvements in Learning Outcomes and Alternative Explanations

The analysis of both quantitative and qualitative data from the main study suggests that the intervention was very effective in helping an entire class of students revise physics and improve their test scores. The students also responded very positively to the intervention. It seems, therefore, that I have the basis for an effective, practical way of helping an entire class of students revise for physics, as well as helping a teacher gain insights into her students' conceptions and thought processes. However, alternative explanations for why the students' test scores improved can be offered. For example, it is possible that this cohort had done particularly well in their practical examination, which accounts for twenty percent of their final physics grade. In other words, it was their outstanding physics practical results and not their performance on the paper-based tests (which the intervention addresses) that caused an improvement in their overall physics grade (when compared to the six-year or three-year average grades, as well as the expected MSG). Also, another possible reason for the students' improved performance could be due to the increased motivation and hard work Ms Er had put into teaching this class, as a result of my presence in her classroom. Additionally, as

mentioned in Chapter Five, other possible reasons for the students' improved performance could be due to my mere presence, which motivated them to work harder on physics, and the novelty effects of working anonymously with fellow students in a computer-mediated environment. I shall now address these alternate explanations in turn.

When the GCE 'O' level results are released, both the students and the school only gets a final grade on the students' performance. In other words, no break-down on how well a student did in a particular section of the examination is provided. Hence, I cannot verify if the students had done particularly well for their practical examinations. However, I did talk to Ms Er on the students' ability in a physics laboratory, and it was her opinion that this cohort of students were not more 'laboratory-savvy' as compared to previous cohorts. In addition, this group of students did not have more time in a physics laboratory as compared to previous cohorts. Hence, it is unlikely that their practical scores were significantly higher than that of the previous cohorts.

With regards to Ms Er having increased motivation and working harder, I believe this was indeed the case. However, she had increased motivation and worked harder not because of my presence, but because the intervention allowed her to have deep insights into her students' thought processes and knowledge base, thereby allowing her to prescriptively address their learning difficulties. Additionally, motivation is reciprocal in nature – as the students were more interested in learning about physics concepts, she became more interested in teaching those concepts, thereby creating the conditions for a virtuous cycle. Also, it is important to note that Ms Er did not spend more time with the students as a result of the intervention. In fact, because Mr Ng had left the teaching profession in June 2009, Ms Er had to take over one of his physics classes (there was no replacement teacher available) and as a result, actually had less time for this cohort of students.

As with the pilot study, it is unlikely that the students were affected by my mere presence, since I found the students to be quite nonchalant in my presence. While I do think that the

students appreciated my presence, I think their appreciation comes from the fact that they could see how the intervention that I had designed and implemented could help them with their revision of physics concepts. Also, their increased interest in physics could be a result of the change in classroom revision practices, which gave them a 'voice' in the classroom. Like Ms Er, they too were caught up in a virtuous cycle and in their case, their interest in physics caused them to spend more time on the subject, thereby improving their physics results, which in turn increased their interest in physics even more. Said differently, while I think that the students in this cohort probably worked harder on physics as compared to previous cohorts, they had done so not because of my presence, but because of the new sociocultural practice for physics revision that the intervention brought about. Finally, given the longitudinal nature of the intervention, it is unlikely that novelty effects was the cause of the improvements.

Having argued that the students' improved learning outcomes were largely due to the effects of the intervention, it is necessary to emphasise that the improvements are not solely due to the intervention. After all, the intervention is revision in nature, and without Ms Er's regular teaching lessons (including some drill and practice), I doubt the students would have shown any improvements. Also, the intervention did not completely cover the entire examinable syllabus, since there are 22 examinable topics but only 16 topics were covered in this study. I believe that if we had covered all the topics, we would have seen an even greater improvement in the students' results. However, it is also arguable that perhaps it was the students' (excellent) performance in the (other) six topics that were not covered in the intervention that caused their results to improve. Naturally, without a complete break-down of scores, these claims are non verifiable.

6.5.2 Discussion on Causes of Students' Difficulties when Solving Physics Problems

As discussed in Chapter One, the predominate reason offered by students is that they perceive physics to be a difficult/hard subject. Students find physics hard essentially because they often experience difficulties in solving physics problems (Byun et al., 2008). For instance,

Tuminaro and Redish (2003) demonstrated that students perform poorly on physics problems involving mathematical tasks largely because of the students' failure to apply the mathematical knowledge they have, or to interpret that knowledge in an appropriate (physics) context. In other words, as well as subject knowledge of physics, successful problem solving in physics often also requires sufficient mathematical knowledge.

Various research endeavours have been undertaken to help students solve physics problems. For example, early research work studied the differences between expert and novice problem solvers (e.g. Simon & Simon, 1978; Larkin & Reif, 1979; Chi et al., 1981; Larkin, 1981) with the view of attempting "to design a general Physics problem-solving instruction that can be taught to students" (Abdullah, 2006, p.12). Later, researchers designed problem-solving models (e.g. Heller & Heller, 2000; Byun et al., 2008) that were targeted at helping students with each stage of the problem solving process. However, as highlighted by Byun et al., (2008), "there is little research on the students' *specific difficulties* in the process of problem solving" (p.87; emphasis added). Without deep insights into students' specific difficulties when they problem-solve, researchers would only be able to offer students generic assistance when prescriptive treatment could be more effective. Hence, in this study, I reviewed specific difficulties the students had during problem solving. My data is gathered from authentic student-dyad discussions collected during collaborative problem-solving that is mediated by synchronous computer-mediated communications technology, and I believe that this difference in data source (as compared to interviews or think-aloud protocol data) could offer interesting insights into the difficulties students encounter with physics problems.

6.5.2.1 More Fundamental than Misconceptions

A popular research track among physics education researchers is the study of students' misconceptions, which is usually defined to mean conceptions that differ from scientific norms and yet are strongly held, stable cognitive structures that affect in a fundamental way how students understand physics concepts and solve physics problems (see Hammer, 1996). Misconceptions are largely attributed to students' prior knowledge (Ogborn, 2004) and against

such a backdrop, it has been recognised that students' preconceptions can often impede their learning and understanding of normative science concepts (for e.g. see McDermott et al., 1987, Bowden et al., 1992; Voska & Heikkinen, 2000).

While the protocol data indicates the prevalence of misconceptions and highlights how misconceptions may impede a student's problem-solving endeavours, it also suggests a much simpler reason for why students have difficulties in solving physics questions – students may simply lack the basic knowledge of the various topics (perhaps due to absenteeism) and, hence, provide naïve, 'unscientific' answers to the questions that were posed (e.g. Zouk's lack of basic knowledge on the topic, pressure, leading her to provide a speed/time-based answer to a pressure question, as illustrated in sub-section 6.4.5.7). Said differently, while students' misconceptions are partially responsible for students' difficulties in solving physics, it would be prudent to check that students actually possess basic knowledge and conceptual understanding on the topics in question. *After all, students cannot be said to have misconceptions if they have no conceptions.* Hence, it would be appropriate to assess students' basic knowledge and understanding prior to embarking on revision sessions that focuses on conceptual and application-based matters.

6.5.2.2 P-Prims caused by Concept Gaps/Awareness



diSessa and colleagues (e.g. diSessa, 1993; Smith et al., 1993/1994) offered an alternative to the misconception perspective. They argue that not all thoughts expressed by students are necessarily derived from stable cognitive structures. Instead, diSessa (as cited in Hammer, 1996) posited the existence of "more fundamental, more abstract cognitive structures he called phenomenological primitives or p-prims. By this view, students respond to a question depends on which p-prims are activated" (ibid, p.102) as part of a knowledge construction process. Hence, students may have difficulties with solving physics problems because a p-prim that is inappropriate with the given context was activated.

The protocol data suggests how p-prims that are inappropriate with a given context might be

activated – when students have weak concept awareness. For instance, Table 6.14 shows how Mumo's lack of concept awareness may have led to the activation of Ohm's p-prim (see diSessa, 1993, p.126-129), leading to an incorrect solution. However, upon recognition of the concept to be applied (in this case, $P=phg$), Mumo was able to obtain the correct solution to the problem.

Hence, students should be taught that when answering questions, they need to make the effort to identify the relevant concepts inherent in the question being asked, and use those concepts in order to answer the question. When given a context-rich or 'everyday' situation-type question, they especially need to resist the urge to provide 'instinctive' answers and, instead, focus on identifying the concepts being assessed in that question. Such an approach should minimise the likelihood of inappropriate p-prims being activated.

Table 6.14: Illustration of weak concept awareness leading to the activation of Ohm's p-prim

Question Posed	Discussion Snippet
<div style="display: flex; justify-content: space-around; align-items: center;"> <div style="text-align: center;"> <p>A</p>  </div> <div style="text-align: center;"> <p>B</p>  </div> </div> <p>Beakers A and B contain tap water. A small hole of the same diameter was made at the middle of both beakers. Which of the following statement is true, and why? [2]</p> <p>a) Water will spurt out further in beaker A than B.</p> <p>b) Water will spurt out equally in beaker A and B.</p>	<p>Veve: i think b</p> <p><i>[Veve revealed to Mumo that she thought the answer was (b). She is correct, but did not provide reasons for her answer]</i></p> <p>Mumo: why??</p> <p>Mumo: i thought bigger area mean more pressure??</p> <p><i>[Here, Mumo questions Veve's answer, and reveals his thought process – he had thought that bigger area (i.e. in beaker B) meant more pressure. Hence, his initial answer is implicitly (c). This could be due to an activation of Ohm's p-prim, whereby the "bigger area" of the water surface and volume (the 'agent') implies more force, and given the same hole size (the 'resistance'), beaker B would spurt water out further than beaker A]</i></p> <p>Mumo: ok i get it</p> <p><i>[Upon reflection of Veve's answer, Mumo claims to "get it"]</i></p> <p>Veve: how?</p> <p><i>[Veve seeks clarification for how Mum 'got it']</i></p>

<p>c) Water will spurt out further in beaker B than A.</p>	<p>Mumo: same density</p> <p>Mumo: same height</p> <p>Mumo: same gravity</p> <p><i>[Here, we see that Mumo has applied the formula $P = phg$. Since the water in both beakers had the same density (p), were at the same height (h), and experienced the same gravitational pull (g), pressure would be the same]</i></p> <p>Veve: so the same rite?</p> <p>Mumo: so ya answer is b</p> <p><i>[Here, we see that both Veve and Mumo agree on the solution]</i></p>
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6.5.2.2 More Fundamental than Misreading and Misinterpretation of the Question

Through their analysis of student responses to multiple-choice questions, Pollitt and Ahmed (2001; see also Crisp et al., 2008) suggest that students' answers to various TIMMS' questions may have more to do with the students' reading and interpretation of a question than with their knowledge on the subject. For example, they reported that when students were asked, "Which of these meals would give you most of the nutrients that you need?", more students selected the option "Vegetables, fruit, and water" instead of the (correct) option "Bread, vegetables, and fish". When the students' selection were analysed according to their countries, the results reveal that students from Norway or Singapore were ten times more likely to select the correct answer than students from South Africa and Colombia. Pollitt and Ahmed suggest that this data indicates that substantial cultural influences regarding the types of food that are considered healthy or nutritious affected how students interpreted the question. Therefore they argue that a question must have construct validity before it can accurately evaluate students' knowledge and abilities on a given topic.

The protocol data reveal a more fundamental issue – students who are weak in the English language might completely not understand the question posed. If students cannot understand the questions posed, then they cannot even attempt to answer the questions. Hence, there is

a need to ensure that the questions posed are not too difficult for such students to grasp. Otherwise, these students could be severely disadvantaged, since their limited command of the language could indirectly (negatively) affect their physics results.

6.5.2.3 *More than (Weak) Mathematical Ability*

In a study of physics problem solving among secondary school students in Turkey, Orhun and Orhun (2002) reported that the most common mistakes students made during problem solving of algebra-based questions were mistakes due to conversion of units, and mistakes on mathematical operations. For example, students incorrectly converted "30g = 3kg" and when solving the equation " $30dg = V_s(3d/2)g$ ", students incorrectly stated that " $V_s = 30 \times 3/2 \Rightarrow V_s = 45$ ". Hence, they suggested that the teaching of mathematics is an important prerequisite for the teaching of physics. However, in a study of undergraduate physics students, Tuminaro and Redish (2003) found that a major source of students' errors while solving mathematics-based physics problems is the students' failure to apply the mathematical knowledge they already possess, or to interpret that knowledge in an appropriate (physics) context. Hence, they suggest that what is needed is not more mathematical lessons, but rather, strategies to help students reframe problems so as to "activate and effectively utilize the relevant mathematical resources [they] already possess" (ibid, p.114).

The protocol data suggests that in addition to mathematical abilities, students need to apply basic logic during physics problem-solving. Hence, to aid in their problem-solving attempts, students need to be taught to consider the logical plausibility of their answers.

In short, the protocol data reveals that non-physics related deficiencies play a big part in how students solve problems. The implication of this finding is that a physics-only intervention might not be adequate to significantly improve students' final physics grade. After all, students who understand all physics concepts taught in class might not do well in an examination if they have a weakness in question comprehension. In other words, students face numerous difficulties when solving physics problems, and a good portion of our students'

difficulties are actually non-physics related. Hence, in order to help students improve, interventions in other domains (e.g. language, mathematics) might be necessary. Further research needs to be conducted to see if there are correlations between language (English), mathematics, and physics results.

6.5.3 Fostering Dialogic Pedagogical Activities

In recent years, there has been increased interest in fostering dialogic pedagogical activities in classrooms (e.g. see Alexander, 2006; Dawes, 2008a; Mercer et al., 2009). This increased interest is largely fuelled by a sociocultural perspective to education, which foregrounds the foundational importance language and dialogue plays in the cognitive development of individuals. However, traditional didactic teaching practices that has existed for centuries still hold sway in classrooms today. As identified by Barnes (1976), there are two types of teachers:

The Transmission teacher sees it as his task to transmit knowledge and to test whether the pupils have received it. To put it crudely, he sees language as a tube down which knowledge can be sent; if a pupil catches the knowledge he can send it back up the tube. Such a teacher does not see speech or writing as changing the way in which the knowledge is held. For the Interpretation teacher, however, the pupil's ability to reinterpret knowledge for himself is crucial to learning, and he sees this as depending on a productive dialogue between the pupil and himself. (p. 142)

Hence, in order to foster dialogic pedagogical activities in a classroom environment, there is a need for teachers to be more "interpretation" and less "transmission" in practice. To help science teachers plan for dialogic teaching, Dawes (2008a) has suggested the use of 'Talking Point' resources, which are based on "a specific science theme and encourage students to consider it in more detail. Talking Points statements are listed in a way that stimulates sequential thinking about the topic and brings out a wide range of ideas for others to hear. They are basically a list of simple statements that encourage thinking, speaking, listening and

learning” (p.3). Figure 6.17 provides an example of a Talking Point resource for the topic, Magnetism.

BOX 1 Talking Points – some examples

Magnetism
Think together to decide if these Talking Points are TRUE or FALSE – or are you UNSURE?
Ask for everyone’s ideas and discuss what you think before deciding.

- 1 Magnets have poles. The north pole of a magnet points north.
- 2 The Earth is a very large magnet.
- 3 Some metals are attracted to magnets – not all. We can say which are.
- 4 Magnetism is strongest near the ends of magnets.
- 5 Magnets are rectangles so that the magnetism can run to each end.
- 6 You can make magnetism from electricity, and electricity from magnetism.
- 7 Magnets don’t work under water.
- 8 Magnets attract each other and repel each other.
- 9 We get the word magnet from the metal magnesium.
- 10 If you cut a magnet in half, you get two magnets.
- 11 We can think of lots of uses for magnets.

Magnets are surrounded by a magnetic force field. We can draw some magnetic characters and their force fields.

Figure 6.17: Magnetism Talking Point resource (Dawes, 2008a, p. 104)

In short, Dawes (2008b) explains that Talking Points are used by teachers in a classroom based on the following setting: Students work in small groups of no more than three in order to discuss the statements made in the Talking Points resources. Prior to working together, students are made aware of the ground rules for thinking together (see Mercer, 2000, chapter two) and the fact that they would be asked “to contribute to a whole-class plenary” on the “content of the Talking Points” as well as “how well the the group talked and worked together” (Dawes, 2008b, p. 33). After sufficient time has lapsed for students to discuss on the Talking Points within their groups, the teacher may then signal for the individual group discussion to stop and the whole-class plenary to start. The teacher may take a Talking Point which “has raised uncertainty or interest and draw on what [the teacher has] heard during group work” (Dawes, 2008a, p.104) and seek contributions from the class, and hence the dialogue in the class is primarily driven from the students' discussion centred on those Talking Points.

This intervention (i.e. CMCPs-PT) contributes to research on dialogic pedagogy in two ways.

Firstly, because the intervention is based on the tenets of sociocultural theory, the constituent components of the intervention (i.e. CMCPs and PT sessions) naturally lends itself towards fostering a dialogic revision environment for physics. In other words, if a science teacher replicates the intervention in accordance to its essence, then the teacher would have fostered a dialogic learning environment by virtue of the fact that the intervention is centred on problem-solving dialogues. Secondly, snippets of students' problem-solving discourse could serve as a Talking Point resource in itself. For example, instead of providing the Magnetism Talking Point resource as depicted in Figure 6.17, teachers can provide discussion snippets of students' problem-solving attempts and have students discuss that instead (see Figure 6.18 for an example).

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Johnny said that it is not possible for the North-pole of a freely suspended bar magnet to always point to the North pole of the Earth, because like poles will repel. Do you agree with Johnny? [1] Provide one reason [1].

Sarsi: is a compass a magnet?
Sarsi: just curious
Yoyo: ??compass ??
Sarsi: yah
Sarsi: is compass a magnet?
Yoyo: yes
Yoyo: we can't see it, it is inside the compass

Xian: i think the earth's magnetic field strength is not very strong
Buddy: explain
Buddy: oh
Buddy: then u mean to say nothing happens
Xian: very likely nothing happens
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Figure 6.18: Using students' problem-solving discourse as a Talking Point resource

I believe that using such problem-solving discourse as a Talking Point resource is particularly appropriate in a secondary school science classroom setting for the following reasons:

- I) Because the resource is centred specifically on a particular question (instead of a broad topic), students see the relevance between 'talking about physics concepts' and 'answering physics questions', which is the main form of assessment used by schools
- II) Because the resource features real students' dialogue, the illustrated discourse could serve as a model for how the students are to discuss with each other
- III) Because the resource is essentially generated from students' discourse, the issues and

concepts illustrated in the resource may resonate with the students, thereby spurring more discussions and debates (especially if the students disagree with one another)

Regardless of the eventual implementation, a distinctive feature of dialogic learning environments lies in the importance a teacher places in summarizing and/or rephrasing students' talk (i.e. "revoicing"; see O'Connor & Michaels, 1996, p.76) in the classroom. Renshaw and Brown (1998) argue that "a student whose contribution has been revoiced by the teacher or another student, is positioned to make a judgement regarding the relevance and acceptability of the revoiced utterance. By revoicing and naming a particular student as the author of the idea the teacher also positions the student in relationship to other participants in the discussion", which is supportive in the building of a more egalitarian and inclusive classroom environment. Talking Points, Prescriptive Tutoring, and Peer Instruction all have this feature, and all have been shown to improve students' learning outcomes, thereby highlighting the relevance and importance of sociocultural theory to individual cognitive development.

6.5.4 Consideration of the Activity Theory Constructs when Replicating the Intervention

While Figure 5.18 provides an Activity Theory instantiation of the intervention implemented in the pilot study, its constructs have largely remained consistent even for the main study. For instance, the intervention's key *artefact* is still the computer 'text-chat' and whiteboard software that allowed students to engage in problem-solving discourse. Also, the *objective* of the intervention remained the same – we want to help students understand physics concepts posed in the questions they are solving, and not drill students to remember facts and memorise 'learning recipes'. From a *rules* perspective, students still needed to abide by the ground rules during the CMCPs sessions (so as to ensure meaningful and productive problem-solving discourse). The *division of labour* had also remained the same in the sense that the students were to articulate their thought processes and knowledge base to each other (and their teachers) during collaborative problem-solving, while the teacher reviewed and analysed the discourse so as to provide prescriptive tutoring based on the students' mental models (and not on a pre-defined lesson plan). From a *community* perspective, I still played an important

role by providing the necessary technical and administrative support needed for the intervention (e.g. setting up the computer laboratories; printing of the discussion logs).

In other words, the Activity Theory instantiation of the intervention depicted in Figure 5.18 captures the *essence* of the intervention, which remained the same during the pilot as well as main study. The intervention essentially causes a change in the sociocultural practices for the revision of physics by changing how students and their teacher interact with each other, thereby changing how they think, act, and feel towards physics. Hence, a reader who wishes to implement the intervention in their own unique setting must realise that the intervention is principally a pedagogical intervention and not a technological one – the use of the text-chat and whiteboard technology alone would be inadequate without the corresponding *rules*, *division of labour*, *community support* (especially technical support; see Soong et al., 2001), and an *objective* to help students understand physics concepts (and not memorise facts or 'learning recipes').

6.6 Chapter Summary

In this chapter, I described the design, implementation and evaluation of my main study. I showed that students in the 2009 batch who were involved in the intervention obtained significantly higher GCE 'O' level physics grades than the six-year and three-year average physics grades of the previous cohorts, in addition to outperforming what the Singapore Ministry of Education had expected of them. Additionally, the three students who were earmarked to drop physics at the end of secondary three had passed the subject, and no student scored below a C5. In addition to improved examination scores, the survey results also show that the students' interest in physics consistently increased throughout the intervention. By and large, the students were very comfortable with being in the intervention, and felt that their biggest improvement due to the intervention lies in their improved understanding of physics concepts and their ability to apply these concepts to solve problems. From an individual revision perspective, many students were spending more time on their revision of physics, as well as having discussions with their classmates on solving physics problems. From a class-

community perspective, most students reported that the intervention had resulted in more discussions between students and teacher, as well as the students themselves. It was their opinion that the increased discussions helped them in understanding physics concept better and/or apply the concepts to questions posed, as well as helped them in dealing with their misconceptions/misunderstandings. The students overwhelmingly agreed that the intervention had been helpful in their their revision of physics concepts, and believe that their juniors (in secondary three) would benefit from the intervention as well. On the whole, they were comfortable with the intervention, despite their many years of exposure to other (less dialogic) revision practices.

From the teacher's perspective, Ms Er had found that being "being involved in this project is a meaningful, enlightening, if not a transformative experience/process". She reported that while she had "been taught the typical elements of good classroom teaching...[and] have used various strategies to understand students' preconceptions/misconceptions to better inform my teaching practice...the amount of knowledge gleaned (mostly generic in nature) in my five years of teaching experience is much less tha[n] the insights that I gained through one year of PT". It is her opinion that the intervention provided a "non-threatening environment" where students can learn from one another and "'talk' about physics", thereby fostering "a collegial and positive learning climate where there is a greater and richer exchange of knowledge and concepts" between her and the students, and had helped her to "identify specific misconceptions and learning difficulties" that her students faced in the learning of physics.

Also included in this main study is an attempt to uncover specific difficulties the students had while solving physics questions. While the literature largely points to misconceptions, p-prims, reading, and mathematical ability as being largely responsible for students' difficulties during problem-solving, the protocol data data indicates that other factors are also responsible in addition to these established causes. These factors include knowledge gaps, concept gaps, mathematical/logical reasoning gaps, weak concept awareness, and an inability to understand the questions posed. In other words, this research study reveals that non-physics related

deficiencies play a big part in how students solve problems and a good portion of our students' difficulties may be considered as non-physics related. Hence, in order to holistically help students improve in their physics problem-solving abilities, interventions in non-physics domains (e.g. language, logical reasoning) might be necessary.

CHAPTER SEVEN

FINAL DISCUSSION, IMPLICATIONS, AND CONCLUSION

In this chapter, I conclude the dissertation by first mapping out my intervention to the C4 Intervention Evaluation model introduced in Chapter Three, emphasising the similarities and differences between my intervention and the seven qualified interventions. Thereafter, I provide a summary of the significant contributions the research study described in this dissertation makes to educational research that aims specifically at improving classroom practices. Next, I provide a discussion on the implications of the findings of this research study (as well as future research work that may be conducted) from the perspective of (i) the practice of physics revision in secondary schools, (ii) designing and implementing ICT-based interventions, and (iii) designing and implementing dialogic learning environments. Finally, I conclude the dissertation by summarising the entire study, as well as sharing my own thoughts on the entire research endeavour reported in this dissertation.

7.1 Mapping the Intervention to the C4 Intervention Evaluation Model

In Chapter Three (section 3.2), I introduced the C4 Intervention Evaluation Model as a means to synthesise and review the qualified physics learning interventions. The model allowed me to highlight the similarities and differences between the interventions from both a practical as well as theoretical perspective. For example, from a practical perspective, the model highlighted that six out of the seven interventions were essentially targeted at a college/university setting, relying on specific affordances offered at these tertiary institutions in order for the interventions to be successfully implemented. On a theoretical perspective, the model revealed that none of the interventions were explicitly based on a sociocultural perspective that privileges dialogue and discourse. Even PI, which is arguably the most dialogic of all the seven interventions, is viewed as being effective essentially because “[i]t continuously actively engages the minds of the students, and it provides frequent and continuous feedback (to both the students and the instructor) about the level of understanding

of the subject being discussed" (Mazur, 2009, p.51). In other words, PI foregrounds constructivist concerns, while sociocultural concerns are in the background. In mapping out my intervention to the C4 Intervention Evaluation Model, I aim to emphasise how my intervention differs from these seven interventions, and illustrate how it contributes to the research community on both practical as well as theoretical fronts.

7.1.1 CMCPs-PT "Context"

My intervention addresses physics at the secondary school curriculum level. Given that the study showed that students of different abilities (e.g. Xian and Chan (high physics abilities), and Dino and Gabo (low physics abilities)) appreciated and benefited from the intervention, the intervention may be said to address students of all abilities at the secondary three and four levels, even though for my research study, the students were typically low academic achievers *based on their PSLE examination scores*. As the intervention is teacher-directed (even though it is student-centred; see section 7.1.3 for a fuller discussion), it requires the presence of a qualified physics teacher to lead and 'orchestrate' the classroom PT sessions. Since the CMCPs-PT intervention addresses the secondary school curriculum, it is bounded by the constraints of the international (or national or state) examination that the school subscribes to (e.g. in the case of secondary schools in Singapore, the GCE 'O' levels). As a revision intervention, the CMCPs-PT intervention requires student pairs to collaboratively work on solving physics problems over a computer network system through a shared text-chat window and a virtual whiteboard. Thereafter, upon analysis of the students' text-chat logs (and whiteboard depictions), the teacher would conduct revision lessons by prescriptively addressing students' problem-solving difficulties (e.g. misconceptions/misunderstandings) based on the students' mental models, and not on a predefined time-table. As the intervention requires students to use computers for discussion purposes, the assistance of an IT laboratory assistant is usually needed. Figure 7.1 provides a summary of my intervention's "context".

Intervention Context					
Curriculum Secondary level physics (GCE 'O' levels)	Students Secondary 3 or 4 students	Teachers Secondary level physics teachers	Institutional Affordances and Constraints Need to take national examinations	Intervention Type Revision intervention	Other Stakeholders IT laboratory assistant

Figure 7.1: CM CPS-PT Intervention "Context"

The CM CPS-PT intervention is most similar to the Diagnoser Project from a "context" perspective, since both interventions address a pre-tertiary physics curriculum involving standardised examinations. In addition, both these revision interventions utilise computers as a crucial 'problem-solving' component of the revision process. However, there are also significant differences between Diagnoser and CM CPS-PT. Firstly, students who use Diagnoser use computers to answer multiple choice questions individually, whereas for CM CPS-PT, students use computers in order to answer a variety of question types (e.g. MCQ, open-ended) with an anonymous partner over a computer network. While the Diagnoser computer system is designed to play the role of a teacher by providing feedback to students based on their answers to the questions posed, it is a teacher that plays this role in the CM CPS-PT intervention. Said differently, while the bulk of the revision interaction is between student and computer for Diagnoser, a significant portion of the revision interaction is between students themselves for CM CPS-PT. Also, while the teacher only plays a supporting role in Diagnoser, the teacher is absolutely essential in CM CPS-PT because it is the teacher that directs the remedial activities during the PT sessions based on the difficulties manifested in the students' problem-solving dialogues, as recorded *in situ* by the computer during the CM CPS sessions.

7.1.2 CM CPS-PT "Content"

As my intervention is not dependent on any specific content or materials, it is concept and topic agnostic. Also, the assessment of effectiveness of my intervention was through historical test scores comparison. Figure 7.2 provides a summary of my intervention's "content".

Intervention Content	
Topics and Concepts Topic and concept agnostic	Assessment Comparison of intervention group with historical data; teacher and students' reflection and surveys

Figure 7.2: CMCPs-PT Intervention "Content"

From a "content" perspective, my intervention is similar to the other topic and concept agnostic interventions, namely, PI, CGPS, and EPP. The distinct advantage in being content agnostic is that content changes (e.g. the inclusion of new content into the syllabus) would not affect the practice of the intervention in any way. However, I recognise that the interventions that rely on specific materials (e.g. the specific questions and options posed in Diagnoser) do so because those materials aid the intervention from an *efficiency* perspective. For example, a teacher may be able to obtain insights into his/her students' conceptions and knowledge base without taking the time to review any logs, since all students need to do is answer the multiple-choice questions (MCQ) posed in Diagnoser. For instance, Figure 7.3 depicts a MCQ (and the relevant distractors/answer) on the topic *Kinematics*. In the question depicted in Figure 7.3, a student is asked to select a description of the horizontal forces acting on a block on a "very slippery table" after it was given "a shove". Conceptually, the answer would be the first option, since "the force to the right is zero" and "the frictional force to the left is very small", as the table is described as being "very slippery". Figure 7.4 shows the 'feedback' that Diagnoser would provide if a student selects the fourth option ("A constant force of motion keeps the block moving to the right"), which is a common misconception.

Diagnoser Tools Save & Quit

Explaining Constant Speed Set 1

Ques. 3.

John's sister put the block on a very slippery table and gave it a shove. After she let go, the block slid across the table with an almost constant speed.

Which statement below best describes the horizontal forces on the block as it slides across the table to the right?

- The force to the right is zero; the frictional force to the left is very small
- The force to the right is greater than the frictional force to the left
- A force of motion to the right is proportional to the speed
- A constant force of motion keeps the block moving to the right

The block is sliding to the right.

Next

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Figure 7.3: A MCQ from Diagnoser on the topic, *Kinematics* (Taken from <http://www.diagnoser.com>)

Diagnoser Tools Save & Quit

Explaining Constant Speed Set 1

It is true that to keep an object moving at a constant speed on a surface with friction you must continue to push or pull on the object.

However, you only need to push with a force equal to the frictional force to keep the object moving at a constant speed.

To test this idea, try pulling a cart at a constant speed with a spring scale on several different surfaces. Notice that as the friction between the cart and the surface decreases, the pulling force to keep it moving at a constant speed also decreases.

Next

Previous Questions
[Ques. 1](#)
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[- Text 1](#)

Figure 7.4: Example of 'Feedback' from Diagnoser (Taken from <http://www.diagnoser.com>)

The immediate feedback that Diagnoser presents to the student (which is relayed to the student's teacher) assumes that the student obtained an incorrect answer because s/he does not understand that a net zero force on an object implies that the object would either remain

at rest, or travel at a constant velocity (i.e. Newton's First Law of Motion). However, while this is a common misunderstanding many students have, it is entirely possible that the students' incorrect answer was a result of not understanding the question, or some other conception. Hence, while Diagnoser (and indeed other non-content agnostic interventions such as Andes) is *efficient* (i.e. doing things well, thus saving time), it is not necessarily *effective* (i.e. doing the right things, thus getting the diagnosis correct). For CMCPST-PT, while it is not necessarily *efficient* (since time is needed to read every peer discussion), it is *effective* since students' perceptions (as well as their reasons and thought processes) are available, thereby offering teachers with a more accurate diagnosis of students' difficulties in solving physics problems. In my opinion, CMCPST-PT strikes an appropriate balance effectiveness and efficiency, providing teachers with a practical trade-off between depth of discovery of students' knowledge and time and effort needed.

7.1.3 CMCPST-PT "Concept"

As expounded in Chapter Two, the theoretical underpinnings of my intervention are sociocultural theory and constructivist learning principles. More specifically, my intervention focuses on creating an environment that promotes and encourages sustained discussions about physics concepts in a non-threatening, fail-safe environment. As a result of the promotion of active problem-solving discourse in order to revise physics, learners natively become active participants in their own journey of learning and discovery (which is the second tenet of constructivism; see section 2.4). Also, because students' collaborative problem-solving endeavours may be transported through time and across space, the teacher may review and analyse those discussions at his/her own convenience. Based on the insights gained from this review and analysis process, the teacher would have specific insights into the students' thought processes and knowledge base, thereby orchestrating his/her lessons around the students' mental models. As a result of the deep insights into the students' existing knowledge, the teacher can assist students in relating what they know to the various views of normative physics concepts (which is the first tenet of constructivism; see section 2.4). As the intervention is teacher-directed and does not make use of existing materials (see 7.1.2), the

teacher is required to prepare the questions to be posed during the CMCPs sessions outside of classroom instruction time. In addition, the teacher is also required to review and analyse the students' collaborative problem-solving discourse and prepare some form of remedial materials based on the students' mental models. Hence, the critical pedagogical concept of CMCPs-PT is essentially to provide students with a *dialogic learning environment* that is *teacher-directed but student-centred*. Figure 7.5 provides a summary of my intervention's "concept".

Intervention Concept			
Theoretical Underpinnings Explicit: Sociocultural theory Implicit: Constructivism	Activities Outside of Classroom CMCPs: Preparation of questions PT: Analysis of protocol data; preparation of PT 'notes'	Activities Inside of Classroom CMCPs: Collaborative problem-solving PT: Student centred remediation	Critical Pedagogical Concept Dialogic learning environment that is teacher-directed but student-centred

Figure 7.5: CMCPs-PT Intervention "Concept"

In my opinion, my intervention is most similar from a "concept" perspective to PI. This is because both CMCPs-PT and PI strongly feature peer discussion as a critical component of learning/revising particular concepts. In addition, the peer discussion for both these interventions are based on specific problems posed to the students. After peer discussion, the teacher would provide remediation based on the students' conceptions. However, there are important differences between PI and CMCPs-PT from both a theoretical as well as practical perspective. From a theoretical perspective, CMCPs-PT pays much more attention to "revoicing" students' opinions and conceptions as compared to PI (see section 6.5.3), since more privilege is given to sociocultural considerations. From a practical perspective, for PI, students are required to read and review textbook materials before attending classes, which might be acceptable in a college/university setting (especially in a high-achieving varsity like Harvard). However, in a mainstream secondary school setting, teachers are expected to teach the content to students during curriculum hours. While it might be possible to implement PI in a more 'revision' context whereby PI is only used after a topic has been taught in class, there are two key obstacles to implementing PI in such a setting. Firstly, many teachers feel that they have incorporated some form of 'group work' or 'peer discussion' during revision lessons. Hence, from that perspective, they might think that there is little difference between PI and

the more common 'group work' approach. In fact, when I was discussing PI with some teachers in the school, most of them commented that they were already "asking students to discuss questions with one another". Because of the similarities in approaches, teachers might not perceive the benefits PI could bring. Secondly, PI requires some maturity from the students in the sense that students are to engage in meaningful discussion with one another. As secondary students are significantly less mature than undergraduates, the quality of their discussions is not often high. In addition, because a teacher can only physically be at one place listening in to one group at a time, the students tend to talk about off-task activities/events when the teacher's attention is on another group. CMCPs-PT avoids these two key obstacles and is appropriate in a secondary school setting. Firstly, the students' discourse during CMCPs is recorded by the computer system. Hence, the students know that any talk about off-task activities/events or disruptive behaviour are traceable to the specific student. Hence, this instils discipline and focus into the students' collaborative problem-solving activities, thereby ensuring a high-quality of discussion. Secondly, because the activities inherent in CMCPs-PT are different from most activities teachers have attempted, they are less likely to make the assumption that the end-results would be the same as per their previous activities, thereby encouraging them to embark on the new practice. Since CMCPs-PT changes how a teacher interacts with his/her students, the change in interaction would cause a change in the way the entire class think, act, and feel towards physics revision. With such a change, practices such as the "revoicing" of students' conceptions may be given more prominence and meaning as compared to past revision practices.

7.1.4 CMCPs-PT "Consequence"

There are important and significant consequences of being involved in CMCPs-PT. As the study has shown, from the students' perspective, the intervention has helped them improve their understanding and application of physics concepts. Also, CMCPs-PT increased the students' interest in physics. As a result of improvements on both the cognitive as well as affective fronts, their physics results have improved significantly. From a teacher's consequence perspective, Ms Er gained deeper insights into her students' thought processes and knowledge

base. Also, because the intervention promoted a collegial and positive learning climate whereby there was rich exchange of knowledge and concepts between teacher and students (and between the students themselves), Ms Er experienced increased satisfaction and fulfilment in her role as a teacher, when she saw the students responding positively to the intervention. As she pointed out, she felt a "sense of pride" when she saw that the students could answer questions that she posed because they understood the physics concepts and not because they have been drilled to remember the solutions. Figure 7.6 provides a summary of my intervention's "consequence".

Intervention Consequence		
<p>Students</p> <p>Improved learning outcomes; Increased interest in learning physics</p>	<p>Teachers</p> <p>Improved understanding of students' misconceptions, difficulties and weakness; increased satisfaction and fulfillment</p>	<p>Other expected consequences</p> <p>Collegial and positive learning climate where there is rich exchange of knowledge and concepts between teacher and students, and students themselves</p>

Figure 7.6: CMCPs-PT Intervention "Consequence"

By and large, the objective of every intervention is to improve students' learning outcomes, and my intervention is no different. Like most of the interventions, there is also increased satisfaction in the learning of physics on the part of the learners. Also, from a teachers' consequence perspective, most of the interventions (e.g. PI, TIIP, Diagnoser, EPP, including CMCPs-PT) are designed such that teachers have an improved understanding of their students' thought processes. After all, teachers are often in the best position to help students learn, and insights into the students' thought processes and knowledge base aid teachers in being more effective educators.

7.1.5 CMCPs-PT Intervention Summary

In sum, I believe that my intervention can stand toe-to-toe with the seven qualified interventions. After all, it helped developed the students' cognitive (e.g. understanding of physics concepts) and affective (e.g. interest in learning physics) domains pertaining to secondary physics education, and aided the teacher in being more effective during revision lessons. Also, it is the only intervention targeted at a secondary level that is concept and topic

agnostic. In my opinion, the intervention is effective because it is explicitly based on a sociocultural perspective that aimed at bringing about a change in classroom pedagogical practices. With a change in practices comes a change in how students and their teacher interacted, thereby changing how everyone felt and acted towards physics revision. This change in pedagogical practices was enabled because, as a collective school-based community, we had agreed that we needed to focus on helping students understand physics concepts better, and the students' problem-solving discussion logs provided us with the means to do so. I recognise that how secondary schools typically divide their labour might make it difficult for the intervention to be immediately implementable, but because the intervention does not require specialised technology or educators to implement, I remain hopeful that teachers would be able to conduct the intervention when the need arises, or even as part of their standard revision practice.

7.2 Summary of Significant Contributions

As discussed in Chapter One, it has been acknowledged that research has a large role to play in the improvement of classroom practices. Given the “crisis” in physics education and the identified need to improve the teaching and learning of physics in secondary science classrooms, it is important that research efforts are put into finding ways of improving secondary physics classroom practices. Also, with the increased use of ICT in classrooms but the “no significant difference” findings various research studies have found, it is important for research to contribute to the design of ICT-infused learning environments that would result in significant improvements in learning outcomes. The research work described in this dissertation contributes to these two areas of interest by illustrating how an intervention that harnesses basic ICT infrastructure readily found in all public schools in Singapore may improve the practice of physics revision in secondary science classrooms.

From a practical perspective, the research study contributes to our community by sharing the design and practice of an intervention that led to significant improvements in students' learning outcomes, both from cognitive and affective fronts. It details an innovative

intervention for secondary school physics revision using common ICT infrastructure, which would help in the utilisation of the intervention in other secondary school classrooms. The intervention had positively impacted both the students and their physics teacher not because it used a different curriculum or teaching tools, but rather because it changed the *practice* of how physics revision was conducted in the classroom. This change in practice was enabled by using ICT as a means for promoting student problem-solving dialogues and aiding the teacher in uncovering the students' thought processes and knowledge base, and made possible because the teacher's (and the students') *objective* of revision lessons had changed from "getting the right answer to the questions posed" to "understanding the physics concepts posed in the questions" (see Chapter Four). Also, given the intervention's sociocultural groundings, it contributes to the growing research interest in designing dialogic learning environments.

From a theoretical perspective, the study illustrates the importance and relevance of sociocultural theory in the design of learning environments that engages the cognitive and affective domains of students, thereby changing them. It shows that an environment that intentionally and explicitly encourages meaningful "talk" between teacher and students, as well as between students themselves, can positively transform and enhance both teaching and learning experiences without the need of fanciful technology (as commonly advocated by educational technology vendors). The study also contributes to an increased understanding of students' difficulties when they solve physics problems. It shows that non-physics related deficiencies may impede students' physics problem-solving attempts regardless of the students' understanding of the physics concepts involved, therefore suggesting that non-physics related interventions may be important to help students solve physics questions better.

In my opinion, the study also informs sociocultural theory by elucidating the conditions in which a teacher may scaffold students' construction of knowledge within their individual zones of proximal development. While several researchers (e.g. see Srivastava & Misra, 2007, p.66; Scott, 2008, p. 84) have identified the zone of proximal development as Vygotsky's most important contribution to learning theory (however, see Edwards, 2005 for an alternate view),

Vygotsky's original conception of the zone is vague, since "a problem in applying the concept of the zone...is that the basic definition of the zone...may characterize virtually any instructional practice [in a classroom]" (Moll, 1990, p. 160). Given that the success of my intervention in improving students' learning outcomes is an indication of the overall effectiveness of the PT sessions, it is likely that the PT sessions effectively created individual zones of proximal developments whereby the teacher helped scaffold the students' knowledge construction efforts. This in turn suggests that an analysis of how the PT sessions were conducted would elucidate the conditions in which a teacher may scaffold students' construction of knowledge within their individual zones of proximal development.

During PT sessions, the students and their teacher *focus their discussions on particular questions which had been collaboratively attempted, and interact in a dialogic manner* in order to *review* the concepts posed in those questions. In my opinion, there are two key reasons why such a classroom practice creates effective individual zones of proximal development. Firstly, on the part of the students, they had worked hard at attempting to solve the questions posed with a peer, and as Howe et al., (2005) have shown, there are incubation and delayed effects associated with peer collaboration. Hence, when those questions are discussed again by the teacher, the students' minds are more 'prepared' and so they gain more from the instruction that follows. Secondly, on the part of the teacher, the activity is dialogic in the sense that during PT, the teacher takes into account the students' mental models when discussing the questions posed. In other words, the teacher is aware of the students' 'baseline' in their respective ZPD. Since the teacher knows the zone's 'baseline' (i.e. students' current knowledge base and thought processes) and 'topline' (i.e. understanding of normative science concepts), instruction to assist students may be more targeted and meaningful. Hence, in short, individual zones of proximal development may be created in a classroom setting when both students and their teacher are 'prepared', even though their 'preparation' involves different endeavours. For the students, they need to be 'prepared' to grapple with the instructions that the teacher would provide, while for the teacher, s/he needs to be 'prepared' by having access into students' current knowledge base and thought processes. Such are the

conditions in which a teacher may scaffold students' construction of knowledge within their individual zones of proximal development.

7.3 Implications for the Practice of Physics Revision in Secondary Schools

7.3.1 Drill-and-Practice (D&P) and CMCPs-PT

Traditionally, the practice of physics revision in secondary classrooms (especially in Singapore) largely revolve around "drill-and-practice" (D&P). During D&P, students are given numerous physics questions (either as a paper-based handout or in a computerised assessment format) to attempt, and whether individually or as a group, the students work at solving those problems posed. The students' problem-solving attempts are usually recorded either on paper (like in a test or examination) or in the computer (where the selected choices or final answer is captured). Based on the correctness of the students' answers, the teacher would provide detailed explanations in class for questions where a significant number of students had difficulty obtaining the correct answer or made mistakes in. Alternatively, the teacher might review the students' work while they are attempting to solve the questions posed during class time, and immediately address any difficulties the students might have.

There are many reasons why a D&P approach to physics revision is the norm in Singapore, but as Ms Er explained, the predominate reason it is commonly practised is to "ensure sufficient repetition of core and popular concepts being tested". As Ms Er had discovered, it is possible to obtain good GCE 'O' level results from a D&P approach, although there are "doubts about the effects...on [the] students' achievement and cognitive development beyond the O levels". However, since D&P appears to deliver good GCE 'O' level results, it is practised in virtually all secondary physics classrooms in Singapore and probably the rest of Asia (see Kim and Pak, 2002, for a discussion on how it is common for students in South Korea to attempt more than 1,000 physics questions in preparation for their examinations). Since D&P is essentially based on repetition (repeatedly attempting many questions), it encourages a practice whereby students (consciously or otherwise) seek to obtain correct answers to the questions posed, while teachers attempt to show students how the correct answers were obtained. As reported

by Ms Er, with D&P, students are “drilled to recognize and remember” answers to various questions regardless of understanding.

As an alternative revision approach, CMCPST-PT differs from D&P in two main areas. Firstly, the *objective* of CMCPST-PT is to help students *understand* the physics concepts in the questions posed. Said differently, while D&P focuses on ensuring students *know the answers* to the questions posed, CMCPST-PT focuses on ensuring that students *understand the physics* evaluated in the questions posed. Secondly, the *interaction* of CMCPST-PT is such that peer discussion is crucial and the teacher “revoices” the students' opinions in order to base remedial instructions on the students' mental models. In other words, while peer discussion is optional and the teacher focuses remedial instructions on an authoritative 'correct answer' in D&P, peer discussion is a crucial component of CMCPST-PT, and the teacher focuses remedial instructions based on a dialogic consideration of what the students said (or wrote) vis-a-vis the normative science views.

In my opinion, the CMCPST-PT intervention introduced in this dissertation offers a viable alternative to the D&P approach to physics revision in secondary science classrooms. As Ms Er explained, CMCPST-PT has been shown to improve students' results because the students “were able to make sound use of Physics concepts to answer the questions...something that occurred because they understood and not because they have been drilled to recognize and remember”. Also, because the intervention is concept/topic agnostic and utilises basic ICT infrastructure found in virtually all public secondary schools in Singapore, the barriers to implementing the intervention are low.

The pilot study has shown that the intervention may be utilised strategically to help a small group of students, while the main study has shown that this intervention is also appropriate as a whole-class revision practice. Nonetheless, I recognise that this CMCPST-PT intervention comes at a cost. While reading students' discourse and identifying misconceptions/misunderstandings and/or knowledge gaps is not a difficult process *per se*, it is

a time consuming endeavour. For instance, I observed that it takes teachers about five to ten minutes to provide a detailed explanation of how they arrived at the answer to a fairly complex (e.g. multi-part) physics question in front of a class of students. Hence, in 60 minutes, a teacher could provide detailed solutions to six physics questions, which was about the number of questions I posed per CMCPs session. Given that it takes about 20 minutes to review and analyse each discussion log (based on a CMCPs session of about one and one-quarter hours), just for the pilot study I needed one hour to review and analysis the XG students' discourse. Thereafter, I spent three hours collating the data (mainly students' text-chat snippets) and preparing the PPT 'notes' used during the PT session. Given the dialogic nature of the lesson, each PT session lasted about one and three-quarter hours. Hence, the total time I spent per CMCPs-PT cycle was four hours. Compared to the traditional revision method, where students worked on answering questions posed for an hour before their teacher explained the solutions for another hour, this revision intervention is clearly much more time consuming, for both the teacher as well as the students. In fact, if there were more discussion logs to review and analyse, then the time taken for the teacher would be even greater. In my opinion, the extra time spent helping students understand physics concepts (rather than memorise answers) is beneficial in at least two ways. Firstly, students gain an interest in physics, which is important from a societal perspective (see Gunasingham, 2009) since they would be much more likely to read physics/engineering at post-secondary level. Secondly, students' grades would improve as a result of better understanding.

Over and above the additional time requirement, I recognise that CMCPs-PT alone cannot deal with all aspects of revision, and the D&P approach still has a role to play during revision lessons. For instance, the D&P approach of using worksheets and past examination papers helps students with their procedural and concept-recognition skills, in addition to building discipline and extending their attention span. Indeed, students take *individual high-stake examinations*, and such 'mock examinations' are a legitimate form of preparation for such endeavours. In my opinion, if some form of 'balance' between CMCPs-PT and D&P may be struck, then we would have a holistic revision intervention that would address the students'

cognitive (e.g. understanding), affective (e.g. interest in physics), and conative (e.g. discipline) needs. Future research could be conducted to evaluate what an appropriate 'balance' might be.

7.3.2 Non-Physics Related Deficiencies, IRF exchanges, and CMCPs-PT

As discussed in Chapter Six (section 6.4.5), non-physics related deficiencies account for a sizable amount of difficulty students experience while solving physics problems. Hence, during physics revision lessons, teachers need to pay special attention at ascertaining whether their students are indeed affected by such non-physics related deficiencies. At present, one of the most common ways for physics teachers to identify the difficulties their students have is through the IRF exchange (see Sinclair & Coulthard, 1975). Typically, the teacher initiates (I) some form of discussion with the students by asking a question. A student would provide a response (R), and based on that response, the teacher would provide some form of feedback or follow-up (F), and the exchange could continue resulting in a IRFRF- chain (see Mortimer & Scott, 2003, p.41). While the IRF exchange is commonly used by teachers to gain insights into students' thought processes, Barnes (2008) noted that,

[I]t is surprisingly difficult for teachers to achieve insight into pupils' thinking merely by asking a question and listening to their brief answers....As a result, they may fail to grasp what pupils had been thinking and what would give them useful support. Thus their contribution to the discussion can sometimes be less than helpful in advancing their pupils' thinking. (p.2)

As a revision intervention, CMCPs-PT helps teachers identify both physics and non-physics related deficiencies and helps "teachers to achieve insight into pupils' thinking" not by "asking a question and listening to their brief answers", but rather, by seeing (or more accurately, reading) how students solve physics questions *in situ* with a peer. Because teachers may now see the *process of how* their students are solving the problems (instead of the *outcome of what* the students thought), the teachers' insight into the students' mental model is much

deeper. In addition, the CMCPS process also changes the IRF exchange roles in a significant way – instead of teachers initiating (I) the discussion and expecting students to provide a response (R), students now may initiate a discussion based on a specific difficulty they have encountered, and can expect the teacher to respond to it. For instance, Table 7.1 provides the discussion snippet between Rarty and Chalice. As both Chalice and Rarty were unable to provide a satisfactory reason for their instinctive answers, they apologised to the teacher (“sorry teacher”) and initiated a discussion by asking the teacher to help them with their conceptions (“Pls explain 2 us Ms Er”), which the teacher did during the corresponding PT session.

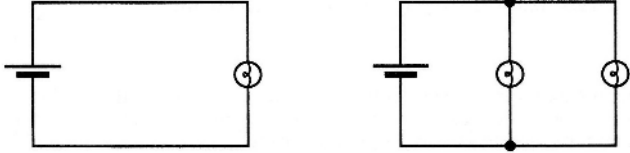
Table 7.1: Students initiating a discussion with the teacher and expecting a response in class

Question Posed	Discussion Snippet
Johnny said that it is not possible for the North-pole of a freely suspended bar magnet to always point to the North pole of the Earth, because like poles will repel. Do you agree Johnny? [1] Provide one reason [1].	Chalice: sorry teacher <i>[After numerous attempts at providing an answer, both Chalice and Rarty were unable to come up with a satisfactory reason to support their answer. Hence, Chalice is apologising as she wants to skip this question and move on to the next]</i> Rarty: its official Rarty: we give up Rarty: :P Rarty: Pls explain 2 us Ms Er <i>[Rarty's statement translates to "Please explain to us, Ms Er". Here, we see Rarty initiating a discussion with the teacher, and expecting her to address their difficulties in class]</i> Rarty: Thx

Table 7.2 provides another example of students' dialogue which was aimed at invoking a response from the teacher. Cullen was having considerable difficulties in answering the question posed because she had difficulty in understanding the question (a non-physics related deficiency). Hence, she expressed her frustration at her inability by directly telling the teacher,

"ms er we are getting mad with this qn!", knowing that the teacher would read the log and respond in class.

Table 7.2: Students' dialogue aimed at invoking a response from the teacher in class

<p>Question Posed</p>	<p>Consider the dispute between two students:</p>  <p>(a) (b)</p> <p>Student 1: "The current through the battery in each circuit is the same. In circuit (b) the current from the battery is divided between the two bulbs – so each bulb has half the current through it that the bulb in circuit (a) has through it."</p> <p>Student 2: "We know the current through each of the bulbs in circuit (b) is the same as through the bulb in circuit (a). That's because the bulbs are all about the same brightness – and bulbs that are equally bright have the same current through them. So the flow through the battery in circuit (b) is more than that through the battery in circuit (a)."</p> <p>Do you agree with student 1, student 2? Explain your reasoning. [2]</p>
<p>Discussion Snippet</p>	<p>Dino: can agree half or not</p> <p>Dino: hehe</p> <p>[Dino is saying that she half agrees with Student 1, and half agrees with Student 2]</p> <p>Cullen: i still cant figure out the part behing</p> <p>Cullen: behind*</p> <p>[Cullen is saying that she cannot figure out the "part behind". I assume this means that she does not understand the second part of what the students are saying]</p> <p>Dino: yaa</p> <p>Cullen: i mean i dont understand</p> <p>[Cullen states that she does not understand...]</p> <p>Dino: as in don understand the sentence?</p> <p>[...in which Dino seeks clarification, asking if Cullen does not understand the sentence. Notice that this is a non-physics related deficiency]</p> <p>Cullen: ya</p> <p>Cullen: aaaaaa</p> <p>Cullen: dont knoww</p>

	<p><i>[Cullen acknowledges that she does not understand the sentence, meaning that she does not understand what the students in the question posed were saying]</i></p> <p>Dino: hahah</p> <p>Dino: i think it means if current in (a) is 4A then current in (b) is 2A each</p> <p><i>[Dino attempts to help Cullen understand what the students are saying]</i></p> <p>Cullen: ms er we are getting mad with this qn!</p> <p><i>[Here, we see Cullen expressing her frustration at her inability to understand the question. Notice that she is directly addressing the teacher, thereby expecting the teacher to response to her difficulty with this question in class]</i></p>
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Hence, CMCPST can help teachers to identify non-physics related deficiencies, as well as extend the IRF exchange by providing opportunities for students to initiate discussions at the specific moment of need. After all, as Barnes (2008) observed, "it will always be the pupil who has to do the learning" (p.2) and "[o]nly pupils can work on understanding: teachers can encourage and support but cannot do it for them" (p. 4). It therefore makes complete sense to have students initiate discussions with their teachers, and CMCPST is entirely supportive of such a practice. Future research should be conducted to look at the extent to which changing the "ground rules" to encourage student-initiated discussions would lead to an increase of such a practice.

7.4 Implications for Research on Designing and Implementing ICT-based Interventions for Physics Education

7.4.1 Peeking Inside Students' Thought Processes

The relative ease at which a researcher can peek inside students' thought processes and knowledge base, as seen from the protocol data provided by CMCPST sessions, has significant research implications. Unlike transcriptions of verbal discourse, a text-chat log is a unique communications record that is actually meant to be read in order to be understood. However,

it still retains the tentative, constructive and fluid nature of discourse in which we might glean insights into subjects' co-construction process, thereby gaining insights into their individual and collective thought processes and knowledge bases. One direct implication is that analysis of such protocol data will allow us to investigate students' difficulties in solving physics questions. For example, the data can show clearly whether students have misconceptions or misunderstandings, gaps in their knowledge, or some other difficulty. Such insights would be helpful to teachers for planning remedial instruction. Another implication would be in the domain of concept inventories (CIs). At present, a Delphi process (e.g. see Goldman et al., 2008) is arguably the most common method for identifying difficult concepts in various topics. Since the Delphi process relies heavily on the input of (adult) experts, it is mainly from the perspectives of these experts that misconceived concepts are included into CIs. On the other hand, the insights gleaned from the review and analysis of the CMCPs discussion logs provide misconception data from students' perspectives. It would be interesting to compare how closely misconceptions from these two different sources match-up. While I expect that there would be differences, this was not further evaluated in this study, and future research can assess this claim further.

7.4.2 Learning From, Through, and Around Computers

As I have shown in Chapter One (section 1.2), ICT is used in a variety of manner for different reasons in physics classrooms. Given the diverse forms and usage of ICT in classrooms, as well as its potential to transform classroom practices, it makes sense to categorise research in ICT and learning. After all, Gill (1995) noted that “[i]f we want to look for profound changes in educational practices, we need to think about the conceptual framework or models within which teachers and pupils are using computers” (p.72). However, this is not an easy task, and as Andrews and Haythornthwaite (2007) observed, “there is as yet no coherent view of what constitutes research in the field [of ICT and education] nor of how best to undertake it.”

Andrews and Haythornthwaite (2007) suggest a wide, macro framework for examining emergent processes in ICT and learning, depicted by a four-by-four matrix that considers the

various levels of interplay between administration, pedagogy, technology, and community (see p.41 to 44), while Crook (1995) offers a simpler, micro-level framework based largely on the *roles* that computers play in schools. Crook's framework, which may be used to categorise research in computers and learning, is as follows:

- The computer as *tutor* – computers take the role of a teacher and provides direct instruction to students (e.g. via drill-and-practice computer programs)
- The computer as *pupil* – computers play the role of a pupil, allowing students to issue commands into the computer so that students may learn from the computers' response (e.g. the issuing of LOGO commands into a computer so as to learn geometry)
- The computer as *resource* – computers play the role of resource provider, providing students with a wide-array of digital resources (e.g. interactive CD-ROMs)
- The computer as *fabric* – computers play the role of the *medium*, allowing communication and sharing of information to take place (e.g. emails, instant-messaging and virtual educational communities)

At this point, I put forth my own micro-level framework for consideration. As I have mentioned in Chapter One, computer usage in schools would likely lead to educational change and improvements only if they are well-designed to *mediate* specific learning objectives or processes. Hence, based on the concept of *mediation*, it may be considered that ICT provides three distinct *mediating* objectives to a lesson designer or teacher, namely, learning *from*, *around*, and *through* computers.

When an instructor designs his/her lesson such that students are to *learn from* the computer, s/he does so with the specific objective of using computers to help students learn content via the students' direct interaction with the computer alone. In other words, the student and computer form an enclosed learning unit with no connections to other learning units (at least during the student-computer interaction). Reading online books, accessing online courseware (including the highly interactive, highly engaging ones), viewing detailed and engaging animations, playing non-networked video games, programming commands into the computer,

drill-and-practice computer programs – all these fall under the category of *learning from* computers. Crook's framework of the computer as *tutor*, *pupil*, and *resource* all fall under this category. Once again, the 'enclosed' learning unit of student and computer alone for this category is emphasised, and that students are to learn content from the computer is highlighted. Because students and the ICT system form an 'enclosed' learning unit, students *learn from* ICT in Andes and Diagnoser.

When an instructor designs his/her lesson such that students are to *learn through* the computer, s/he does so with the specific objective of using computers as a *medium through which* students may collaborate, interact, discover, and learn with others. The computer may provide instructions, resources and hints, but it is the unique affordance of computer-mediated communications (CMC) in supporting collaborative learning (e.g. reach, asynchronous, synchronous, permanency of the medium) that the instructor is most interested in. Playing networked games (e.g. MMORPG-type games) and students collaboratively solving problems via CMC such as CMCPs-PT fall under the category of *learning through computers*. Crook's framework of the computer as *fabric* falls under this category, though he focused on the network and information dissemination aspects much more strongly in his paper. Once again, I emphasise the collaborative aspect of using the computer as a medium of communication for knowledge co-construction between teachers and students, or between the students themselves. Because students use ICT as a medium for problem-solving, students *learn through* ICT in CMCPs-PT.

When an instructor designs his/her lesson such that students are to *learn around* the computer, s/he does so with the specific objective of using computers to help students work collaboratively with others using the computer (or things provided by the computer) as a centre-piece for discussion. In other words, while the computer may provide instructions, resources and hints, it is the *collaborative work around the computers* that the instructor is most interested in. Teachers and students working collaboratively around interactive whiteboards (e.g. see Gillen et al., 2007), children working collaboratively around interactive

computer programs (e.g. visit <http://thinkingtogether.educ.cam.ac.uk/>) – all these fall under the category of *learning around* computers. I again emphasise the collaborative aspect of using the computer as a centre-piece for knowledge co-construction between teachers and students, or between the students themselves. Because students work collaboratively with “clickers” in PI and with data loggers and visualisation systems in ABPS, students actually *learn around* ICT in both PI and ABPS. Also, because ICT transports students' discussion logs (for CMCPs-PT) and selections (for Diagnoser) through time and across space, students also *learn around* ICT in both CMCPs-PT and Diagnoser.

In my opinion, the majority of research on ICT and education appears to be centred on *learning from* computers. For example, Krusberg (2007) identified Physlets Physics (Physlets; e.g. Christian & Belloni, 2001), Andes Intelligent Tutoring System (Andes; e.g. VanLehn et al., 2005), and Microcomputer-Based Laboratory (MBL; e.g. Redish, 2003) as “emerging technologies in physics education” (p.401). Out of these three “emerging technologies”, Physlets and Andes require students to *learn from* ICT, while for MBL, students *learn around* the data and charts that MBL produces.

More research should be focussed on *learning through* computers. As a research community, we are already familiar with the generic advantages of using computers as a medium through which learning can occur. However, I think the uniqueness of the permanency of the electronic medium is an area often overlooked by researchers and designers of learning environment. I believe the permanency property offered by the electronic medium can provide teachers with a powerful tool to better understand students' thinking, thereby facilitating student learning better, and the CMCPs-PT intervention reported on in this dissertation is one such example. In the case of CMCPs-PT, computers were used predominately due to their ability to hide identities (the students did not know who they were working with) and ability to easily record the entire knowledge negotiation process between the student dyads. In other words, the computer played a subsidiary role to the teacher, and was integrated into the wider learning process by providing the teacher with information that was otherwise too difficult and time

consuming to obtain – students' exact thought processes when solving problems.

More research also needs to be conducted on learning around computers, given its potential to turn simple (or behavioural interactive multimedia) content into opportunities for knowledge co-construction and the appropriation of higher order thinking and functioning (e.g. see Herrington & Standen, 1999). An example of work in this area is the work by Mercer and colleagues (Mercer et al., 1999; see also Wegerif, 1996; Wegerif et al., 1998; Mercer, 2000 (chapter 6); Wegerif, 2004), whose research findings have been incorporated into the UK's National Strategies for primary and secondary education. In their research, they designed an intervention to help develop primary school children's talk and the development of reasoning. Briefly, they taught teachers who in turn taught students the ground rules for "exploratory talk". Next, using the ground rules and other scaffolds as guides, students worked with each other around a specially-designed computer program in order to collaboratively obtain solutions for the questions posed. Such collaborative efforts, together with teacher-led discussions, led to an increase in the children's exploratory talk, raised achievement in group situations and raised achievement in individual work as assessed by the Raven's standard progressive matrices non-verbal reasoning test (see Raven et al., 1995). Computers were used predominately due to their non-judgemental and patient 'nature', as well as their ability to frame the dialogues students were supposed to be engaged in. In other words, the computer was integrated into the wider learning process and situated within a context appropriate for its use.

7.5 Implications for Research on Designing and Implementing Dialogic Learning Environments

The institution of formal, school-based education has been with us for centuries, and in my opinion, is unlikely to change in form, structure or style any time soon. As such, we need to work within the constraints inherent in schools, including the fact that there are many more students than there are teachers, and lessons which are based on a standardised curriculum are conducted within definite starting and ending periods. In such a scenario, Mercer (e.g.

Mercer, 2010) has proposed that “talking skills” be taught to both students and teachers so that they may learn how to talk and work together, and hold “reasoned discussions” with each other during class. After all, from a sociocultural perspective, language is a tool for thinking and individual cognitive development, which occurs mainly through dialogue (see Mercer, 2000, chapters 1 and 6).

While I fully support the notion of engaging students in meaningful dialogue, it is important to recognise that *dialogue does not necessarily have to be verbal in nature*, even though verbal dialogue account for a significant portion of all communications between teachers and students in a school-based setting. Verbal communication is not an end in itself. Rather, it is a means to an end, and in the context of formal schooling, a key objective is for students to develop cognitively in, say, physics, mathematics, or history. Such cognitive developments occur because students are able to make sense and internalise events that were played out on a social plane (e.g. see Wertsch, 1991), and this sense-making and internalisation process are *mediated by language and facilitated by dialogue* which need not be spoken or verbal in nature (e.g. they may be in a written form, or perhaps even communicated by hand-signals). The ultimate point is simple and obvious – verbal communication is but one form of dialogue, and researchers (and practitioners) should consider evaluating other forms of dialogue in order to facilitate students' cognitive development. After all, we need to recognise, as Thorndike had, that the “chief excellence” of the practice whereby teachers do most of the talking in classrooms “is economy...[and] in some cases this advantage alone justifies its use” (1912, p.189, as cited by Spencer, 1991, p.6). Hence, it is unlikely that students would get enough time to verbally express their opinions and conceptions to their teacher in a traditional classroom setting, and unless the classroom setting changes (e.g. to a situation whereby the student-to-teacher ratio is much smaller), then other forms of (non-verbal) dialogic engagements with students should be explored. Additionally, there is a need to recognise that a dialogic learning environment does not necessarily imply one that is centred on verbal discourse. As Mortimer and Scott clarified, a “*dialogic* communicative approach [is one] where attention is paid to more than one point of view” and where “more than one *voice* is heard and

there is an exploration...of ideas" (2003, p.33-34; emphasis in original). Hence, so long as teachers "revoice" students' conceptions and help them reinterpret knowledge for themselves (see Chapter Six, section 6.5.3), then it may be considered that such a learning environment is dialogic in nature, and supportive of sociocultural practices in aiding the cognitive (and probably also affective) development of students.

7.6 Dissertation Conclusion

7.6.1 Dissertation Summary

In sum, this dissertation reported on the design, implementation, and evaluation of my intervention for the revision of physics in a mainstream public secondary school in Singapore. This intervention was conducted over a one-year period, and involved students who were taking their GCE 'O' level physics examination after immersion in the intervention, which was conducted as part of their regular physics revision curriculum.

Based on sociocultural theory, the intervention changed the practice of how physics revision was conducted in a particular secondary physics classroom in Singapore. Consisting of a computer-mediated collaborative problem-solving (CMCPS) component and a prescriptive tutoring (PT) component, the CMCPS portion of the intervention required the students to follow basic "ground rules" for computer-mediated problem-solving of physics questions. Basically, a student selected a computer to work from, and was randomly paired with another student working from a different computer in order to solve physics questions through the computer network by way of a virtual shared text-chat box and whiteboard provided for by the computer-mediated communications software (NetMeeting, a fee-free software pre-installed in all Windows XP machines). After the CMCPS session, the students' problem-solving dialogues were captured and printed for review and analysis by the students' physics teacher. During the PT session, the teacher prescriptively addressed the students' misconceptions, misunderstandings, and other problem-solving difficulties that the students exhibited during their CMCPS session. In other words, revision lessons were primarily based on the students' mental models and secondarily on physics concepts, instead of the other way round. Hence,

the basis for instruction during remedial lessons came from students' protocol data, rather than a pre-specified timetable.

The intervention was evaluated in two stages. First, a small-scale (pilot) study was conducted in order to evaluate whether the intervention was effective in promoting improved learning outcomes as measured by the students' physics grades. This small-scale study was also conducted to ascertain if the XG students were interested in being involved in the intervention for the whole of the academic year 2009. Also, the small-scale study allowed the students' physics teacher to evaluate the intervention in order to recommend whether the larger-scale (main) study should be conducted.

Given the statistically significant improvements in the students' results and the overall positive findings of the small-study scale (which utilised a control group (CG) / alternate intervention group (AG) / experimental group (XG) with pre- and post-test research design), the intervention was conducted for the entire class during the main study. In order to evaluate the effectiveness of the intervention during the main study, the cohort's actual GCE 'O' level physics results were compared with their expected grades (as given by the Singapore Ministry of Education based on the students' primary school's results). Also, the students' 'O' level physics results were compared with the average physics results obtained by previous cohorts. The quantitative data indicated that the intervention for physics revision appears to be effective in helping the entire class of students revise physics concepts, resulting in improved test scores, while the qualitative data indicated that as a result of the involvement in the intervention, the students' interest in physics had increased over time such that by the end of the intervention, every student either "very much liked" or "liked" learning physics. The physics teacher also appreciated the intervention, and had found that from the perspective of knowing what students are thinking, "the amount of knowledge gleaned (mostly generic in nature) in my five years of teaching experience is much less than the insights that I gained through one year of PT", and reflected that "being involved in this project is a meaningful, enlightening, if not a transformative experience/process".

From a practical perspective, the research study contributes to our community by sharing the design and practice of an effective intervention that addresses secondary science classrooms, which has been identified as being crucial in dealing with the “crisis” in physics education. It also contributes to the growing research interest in designing dialogic learning environments.

From a theoretical perspective, the study illustrates the importance and relevance of sociocultural theory in the design of learning environments that engage the cognitive and affective domains of students, thereby changing them. It shows that an environment that intentionally and explicitly encourages meaningful “talk” between teacher and students, as well as between students themselves, can positively transform and enhance both teaching and learning experiences without the need of fanciful technology (as commonly advocated by educational technology vendors).

7.6.2 Final Reflections

When I proposed to embark on the research study reported in this dissertation, most of my fellow PhD candidates thought that I had lost my mind. “It's so risky!”, one exclaimed. “What if, after one year, there are no improvements? Wouldn't you have to restart your research from scratch then?”, another rhetorically asked. For me, it was my own personal belief in the objective of educational research that led me down this “risky” path (see Chapter One, section 1.1). More than that, I was personally convinced that I 'knew' what the problems were in secondary science classrooms, and that I could 'fix' them. As it turned out, while I was correct in some areas, I was mostly wrong in others. I shall start by providing a brief description of some of the occasions whereby I was 'wrong', and end on a positive note by presenting a brief account of some of the times when I was 'correct'.

In retrospect, while I conceptually understood the challenges and difficulties in conducting real-world research and had proclaimed in a methodological paper (in April 2008) that I “am confident that I should be able to handle doing research in the booming, buzzing confusion of

real-world classrooms”, nothing could have prepared me for the harsh reality and events in real-world classrooms, which range from minor irritations to significant jeopardies. For example, the Vice-Principal had assigned me with a personal desk in a room where the IT assistants and relief teachers occupied. However, the other relief teachers (who had to share desks), started using my desk partly due to a shortage of workspace and partly because I was not considered to be a 'real' teacher, and so could well afford to share my space with them. As a result, I could not place my research or personal articles there, which made it more difficult for me to do work in school, which was a bugbear for me. An example of an event that could have jeopardised the entire research study was when Xian and Chan requested to be excused from the study even before attempting it. Fortunately, they chose to stay on with the intervention after experiencing it.

In all honesty, up until before I concluded the pilot study, I had initially thought that all students who had undergone my intervention would obtain a distinction grade for physics for their GCE 'O' level examination. This was because I was confident in the theoretical foundations that my intervention was based on, and firmly believed that it would transform educational practices and drastically improve students' results. I only started having concerns about the students' results when I noticed that absenteeism (by both students and teachers) and other non-physics related deficiencies were negatively affecting the students' problem-solving abilities and hence, their results. In addition, I experienced first-hand how teachers felt when they, in their opinion, have very clearly addressed a specific student's misunderstanding, only to have that student 'repeat the same mistake' again. When I myself was a student in school, I had thought that teachers were angry when I repeated my mistakes. However, now that the roles were reversed, I realised that it was not *anger* that the teachers felt, but rather, *anguish* – teachers work so hard at helping students learn from their mistakes and yet, these students somehow doggedly hold onto their previous conceptions. What kept me going was my conviction that I was doing something meaningful, and Ms Er's constant reminders that “Bartley students are like that. We must repeat many times then they will get it.”

On the positive side, I started this research study because I believed that classroom practices needed to change, and I knew that since teachers and students are focused on good examination results, any change to classroom practices needed to be predicated on improving students results. Hence, I had planned for a small-scale pilot study to demonstrate the effectiveness of the intervention in improving students' results, and given the careful planning from both methodological (e.g. research questions and methods) as well as theoretical (e.g. cognitive development theories and pedagogy) perspectives, the students' results improved, thereby allowing me to conduct the main study and showing that the intervention was effective even in a whole-class set-up.

Most importantly, my greatest sense of pride and joy lies in the fact that my intervention had positively impacted the lives of these 23 physics students (some more than others) and their teacher. At the end of the intervention before I returned to Cambridge to write-up this dissertation, many students had come up to me in school and told me that they "really learnt a lot" from "my method", and I even received an email from Zouk thanking me for what I had done for them, explaining that "It's all the interactive way of learning you introduce that build up my interest in physics". Bearing in mind that the students had actually not yet taken their 'O' level examinations and thought that they would probably not see me for the foreseeable future, their expressions of gratitude made it easier for me to believe that I had indeed done a good job. Now, even with the benefit of hindsight on all the difficulties and challenges doing real-world research encompasses, I would still do it again.

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APPENDICES

Appendix 4.1: Primary School Leaving Examination Scores for Public Schools in Singapore (Page 1 of 5)



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School Information Service

Total Number of Schools found : 160

Selected Search Criteria
 Level of Education : Secondary
 PSLE Aggregate : Express

Current PSLE range available is for 2008

Current awards available is for 2009

Please click ▲ to sort ascending or click ▼ to sort descending

LEGEND			
Special Awards	SEA	School Excellence Award	🏆
	SDA	School Distinction Award	🏅
Level Two Awards	ODA	Outstanding Development Award	🌟
	BPA	Best Practice Award	★
	SAA	Sustained Achievement Award	★
Level One Awards	DA	Development Award	☆
	AA	Achievement Award	☆

The ODA and DA given out in 2005 only include the National Education (NE) category.

SECONDARY SCHOOL	Achievements in 2009					From Non-Affiliated Schools (Aggregate Range of 2008 Primary 6 pupils posted to 2009 Secondary 1)					SECONDARY SCHOOL	
	Special Award	AA & SAA Academic Value-added	Physical & Aesthetics	Character Development	BPA	Special	Express	Normal (A)	Normal (A) EM3	Normal (T)		Normal (T) EM3
ADMIRALTY SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆		-	206 - 239	171 - 196	-	115 - 159	71 - 112	ADMIRALTY SECONDARY SCHOOL
AHMAD IBRAHIM SECONDARY SCHOOL			☆☆☆☆	☆☆		-	223 - 256	180 - 195	-	130 - 158	90 - 125	AHMAD IBRAHIM SECONDARY SCHOOL
ANDERSON SECONDARY SCHOOL	🏆	☆☆	☆☆☆☆	☆☆	★	-	248 - 268	189 - 199	-	146 - 159	107 - 128	ANDERSON SECONDARY SCHOOL
ANG MO KIO SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆		-	227 - 251	182 - 199	-	140 - 152	100 - 120	ANG MO KIO SECONDARY SCHOOL
ANGLICAN HIGH SCHOOL			☆☆☆☆	☆☆		-	244 - 267	-	-	-	-	ANGLICAN HIGH SCHOOL
ANGLO-CHINESE SCHOOL (BARKER ROAD)*		☆☆	☆☆☆☆	☆☆		-	-	-	-	-	-	ANGLO-CHINESE SCHOOL (BARKER ROAD)*
ANGLO-CHINESE SCHOOL (INDEPENDENT)*	🏆		☆☆☆☆	☆☆	★★★	-	253 - 269	-	-	-	-	ANGLO-CHINESE SCHOOL (INDEPENDENT)*
ASSUMPTION ENGLISH SCHOOL		☆☆	☆☆	☆☆		-	188 - 231	154 - 194	119 - 127	116 - 150	66 - 112	ASSUMPTION ENGLISH SCHOOL
BALESTIER HILL SECONDARY SCHOOL		☆☆	☆☆	☆☆	☆☆	-	188 - 230	152 - 187	113 - 117	127 - 148	60 - 103	BALESTIER HILL SECONDARY SCHOOL
BARTLEY SECONDARY SCHOOL		☆☆	☆☆	☆☆	☆☆	-	188 - 240	152 - 186	113 - 122	131 - 151	72 - 110	BARTLEY SECONDARY SCHOOL
BEATTY SECONDARY SCHOOL		☆☆	☆☆	☆☆	☆☆	-	217 - 238	172 - 192	-	137 - 156	96 - 132	BEATTY SECONDARY SCHOOL
BEDOK GREEN SECONDARY SCHOOL			☆☆	☆☆	☆☆	-	212 - 241	173 - 199	-	134 - 159	94 - 110	BEDOK GREEN SECONDARY SCHOOL
BEDOK NORTH SECONDARY SCHOOL			☆☆	☆☆	☆☆	-	188 - 228	152 - 187	114 - 128	137 - 155	94 - 112	BEDOK NORTH SECONDARY SCHOOL

Appendix 4.1: Primary School Leaving Examination Scores for Public Schools in Singapore (Page 2 of 5)

BEDOK SOUTH SECONDARY SCHOOL		☆☆	☆☆☆☆☆☆☆☆	-	209 - 233	161 - 197	-	126 - 159	87 - 106	BEDOK SOUTH SECONDARY SCHOOL
BEDOK TOWN SECONDARY SCHOOL		☆☆	☆☆☆☆☆☆☆☆	-	189 - 230	152 - 186	113 - 127	129 - 155	61 - 113	BEDOK TOWN SECONDARY SCHOOL
BEDOK VIEW SECONDARY SCHOOL		☆☆	☆☆☆☆☆☆☆☆	-	218 - 234	172 - 197	-	138 - 159	99 - 113	BEDOK VIEW SECONDARY SCHOOL
BENDEMEER SECONDARY SCHOOL		☆☆	☆☆☆☆☆☆☆☆	-	194 - 235	155 - 190	130 - 130	135 - 151	95 - 111	BENDEMEER SECONDARY SCHOOL
BISHAN PARK SECONDARY SCHOOL		☆☆	☆☆☆☆☆☆☆☆	-	188 - 237	152 - 187	115 - 121	138 - 149	71 - 111	BISHAN PARK SECONDARY SCHOOL
BOON LAY SECONDARY SCHOOL		☆☆	☆☆☆☆☆☆☆☆	-	189 - 241	165 - 189	-	136 - 157	96 - 112	BOON LAY SECONDARY SCHOOL
BOWEN SECONDARY SCHOOL			☆☆☆☆☆☆☆☆	-	221 - 245	182 - 199	-	113 - 150	67 - 112	BOWEN SECONDARY SCHOOL
BROADRICK SECONDARY SCHOOL			☆☆☆☆☆☆☆☆	-	188 - 229	152 - 188	118 - 138	128 - 149	87 - 109	BROADRICK SECONDARY SCHOOL
BUKIT BATOK SECONDARY SCHOOL		☆☆	☆☆☆☆☆☆☆☆	-	227 - 239	177 - 199	-	140 - 157	102 - 115	BUKIT BATOK SECONDARY SCHOOL
BUKIT MERAH SECONDARY SCHOOL		☆☆	☆☆☆☆☆☆☆☆	-	188 - 243	152 - 187	115 - 126	124 - 151	82 - 112	BUKIT MERAH SECONDARY SCHOOL
BUKIT PANJANG GOVT. HIGH SCHOOL	♂	☆☆	☆☆☆☆☆☆☆☆	★	244 - 262	192 - 199	-	149 - 159	110 - 120	BUKIT PANJANG GOVT. HIGH SCHOOL
BUKIT VIEW SECONDARY SCHOOL		☆☆	☆☆☆☆☆☆☆☆	-	210 - 227	159 - 196	-	130 - 153	62 - 112	BUKIT VIEW SECONDARY SCHOOL
CANBERRA SECONDARY SCHOOL			☆☆☆☆☆☆☆☆	-	199 - 228	166 - 198	-	136 - 159	97 - 116	CANBERRA SECONDARY SCHOOL
CATHOLIC HIGH SCHOOL *	♂	☆☆	☆☆☆☆☆☆☆☆	★	249 - 264	-	-	-	-	CATHOLIC HIGH SCHOOL *
CEDAR GIRLS' SECONDARY SCHOOL	♀	☆☆	☆☆☆☆☆☆☆☆	★	244 - 271	-	-	-	-	CEDAR GIRLS' SECONDARY SCHOOL
CHAI CHEE SECONDARY SCHOOL			☆☆☆☆☆☆☆☆	-	188 - 230	152 - 182	114 - 122	-	-	CHAI CHEE SECONDARY SCHOOL
CHANGKAT CHANGI SECONDARY SCHOOL			☆☆☆☆☆☆☆☆	-	192 - 223	156 - 189	131 - 131	127 - 157	75 - 128	CHANGKAT CHANGI SECONDARY SCHOOL
CHESTNUT DRIVE SECONDARY SCHOOL		☆☆	☆☆☆☆☆☆☆☆	-	188 - 238	152 - 185	113 - 133	125 - 143	69 - 91	CHESTNUT DRIVE SECONDARY SCHOOL
CHIU KATONG CONVENT *		☆☆	☆☆☆☆☆☆☆☆	★	228 - 241	179 - 198	-	127 - 150	83 - 115	CHIU KATONG CONVENT *
CHIU SECONDARY (TOA PAYOH) *	♂	☆☆	☆☆☆☆☆☆☆☆	★	246 - 257	186 - 199	-	-	-	CHIU SECONDARY (TOA PAYOH) *
CHIU ST. JOSEPH'S CONVENT *		☆☆	☆☆☆☆☆☆☆☆	★	224 - 243	180 - 192	-	123 - 155	85 - 108	CHIU ST. JOSEPH'S CONVENT *
CHIU ST. NICHOLAS GIRLS' SCHOOL *	♂	☆☆	☆☆☆☆☆☆☆☆	★	249 - 276	-	-	-	-	CHIU ST. NICHOLAS GIRLS' SCHOOL *
CHIU ST. THERESA'S CONVENT *		☆☆	☆☆☆☆☆☆☆☆	★	232 - 240	178 - 195	-	130 - 147	87 - 109	CHIU ST. THERESA'S CONVENT *
CHONG BOON SECONDARY SCHOOL			☆☆☆☆☆☆☆☆	★	188 - 265	152 - 189	113 - 128	131 - 148	78 - 108	CHONG BOON SECONDARY SCHOOL
CHRIST CHURCH SECONDARY SCHOOL			☆☆☆☆☆☆☆☆	-	196 - 230	170 - 188	-	134 - 159	90 - 114	CHRIST CHURCH SECONDARY SCHOOL
CHUA CHU KANG SECONDARY SCHOOL		☆☆	☆☆☆☆☆☆☆☆	-	217 - 235	178 - 196	-	140 - 154	102 - 134	CHUA CHU KANG SECONDARY SCHOOL
CHUNG CHENG HIGH SCHOOL (MAIN)	♂	☆☆	☆☆☆☆☆☆☆☆	★	239 - 265	-	-	-	-	CHUNG CHENG HIGH SCHOOL (MAIN)
CHUNG CHENG HIGH SCHOOL (YISHUN)			☆☆☆☆☆☆☆☆	★	230 - 268	182 - 198	-	141 - 153	101 - 127	CHUNG CHENG HIGH SCHOOL (YISHUN)
CLEMENTI TOWN SECONDARY SCHOOL	♂	☆☆	☆☆☆☆☆☆☆☆	★	233 - 245	182 - 197	-	140 - 154	101 - 116	CLEMENTI TOWN SECONDARY SCHOOL
CLEMENTI WOODS SECONDARY SCHOOL		☆☆	☆☆☆☆☆☆☆☆	-	188 - 232	152 - 189	113 - 117	125 - 125	60 - 101	CLEMENTI WOODS SECONDARY SCHOOL
COMMONWEALTH SECONDARY SCHOOL		☆☆	☆☆☆☆☆☆☆☆	★	238 - 261	184 - 199	-	135 - 152	96 - 111	COMMONWEALTH SECONDARY SCHOOL
COMPASSVALE SECONDARY SCHOOL		☆☆	☆☆☆☆☆☆☆☆	★	217 - 243	178 - 198	-	127 - 151	88 - 110	COMPASSVALE SECONDARY SCHOOL
CORAL SECONDARY SCHOOL		☆☆	☆☆☆☆☆☆☆☆	★	214 - 232	178 - 197	-	136 - 159	97 - 130	CORAL SECONDARY SCHOOL
CRESCENT GIRLS' SCHOOL	♀	☆☆	☆☆☆☆☆☆☆☆	★	242 - 270	-	-	-	-	CRESCENT GIRLS' SCHOOL
DAMAI SECONDARY SCHOOL			☆☆☆☆☆☆☆☆	★	207 - 254	160 - 194	-	138 - 158	100 - 110	DAMAI SECONDARY SCHOOL
DEYI SECONDARY SCHOOL			☆☆☆☆☆☆☆☆	★	215 - 236	174 - 197	-	137 - 152	97 - 111	DEYI SECONDARY SCHOOL
DUNEARN SECONDARY SCHOOL		☆☆	☆☆☆☆☆☆☆☆	★	204 - 237	168 - 187	-	128 - 156	88 - 112	DUNEARN SECONDARY SCHOOL
DUNMAN HIGH SCHOOL	♀		☆☆☆☆☆☆☆☆	★	260 - 282	-	-	-	-	DUNMAN HIGH SCHOOL

Appendix 4.1: Primary School Leaving Examination Scores for Public Schools in Singapore (Page 3 of 5)

DUNMAN SECONDARY SCHOOL	♫	☆☆☆	☆☆☆☆☆☆	☆☆	-	234 - 261	194 - 199	-	148 - 159	109 - 113	DUNMAN SECONDARY SCHOOL	
EAST SPRING SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆	-	212 - 233	178 - 193	-	111 - 154	69 - 110	EAST SPRING SECONDARY SCHOOL	
EAST VIEW SECONDARY SCHOOL			☆☆☆☆	☆☆	-	188 - 235	160 - 186	-	124 - 155	70 - 108	EAST VIEW SECONDARY SCHOOL	
EVERGREEN SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆	-	220 - 243	182 - 199	-	132 - 159	93 - 133	EVERGREEN SECONDARY SCHOOL	
FAIRFIELD METHODIST SCHOOL (SECONDARY)*	♫	☆☆☆	☆☆☆☆	☆☆	★	-	246 - 260	188 - 199	-	148 - 158	107 - 113	FAIRFIELD METHODIST SCHOOL (SECONDARY)*
FAJAR SECONDARY SCHOOL			☆☆☆☆	☆☆	-	188 - 243	163 - 189	-	127 - 154	88 - 113	FAJAR SECONDARY SCHOOL	
FIRST TOA PAYOH SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆	-	188 - 233	153 - 190	114 - 124	119 - 151	78 - 114	FIRST TOA PAYOH SECONDARY SCHOOL	
FUCHUN SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆	-	188 - 242	159 - 185	-	109 - 155	65 - 128	FUCHUN SECONDARY SCHOOL	
FUHUA SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆	-	232 - 251	182 - 199	-	141 - 158	103 - 114	FUHUA SECONDARY SCHOOL	
GAN ENG SENG SCHOOL		☆☆	☆☆☆☆	☆☆	-	227 - 259	180 - 198	-	138 - 152	99 - 112	GAN ENG SENG SCHOOL	
GEYLANG METHODIST SCHOOL (SECONDARY)*			☆☆☆☆	☆☆	-	226 - 239	187 - 193	-	-	-	GEYLANG METHODIST SCHOOL (SECONDARY)*	
GREENDALE SECONDARY SCHOOL			☆☆☆☆	☆☆	-	192 - 235	154 - 190	119 - 128	130 - 158	82 - 110	GREENDALE SECONDARY SCHOOL	
GREENRIDGE SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆	-	206 - 231	171 - 188	-	133 - 155	93 - 109	GREENRIDGE SECONDARY SCHOOL	
GREENVIEW SECONDARY SCHOOL			☆☆☆☆	☆☆	-	203 - 252	163 - 190	-	133 - 151	94 - 121	GREENVIEW SECONDARY SCHOOL	
GUANGYANG SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆	-	203 - 234	159 - 199	-	129 - 151	85 - 107	GUANGYANG SECONDARY SCHOOL	
HAISING CATHOLIC SCHOOL		☆☆☆	☆☆☆☆	☆☆	-	228 - 240	185 - 198	-	142 - 158	102 - 110	HAISING CATHOLIC SCHOOL	
HENDERSON SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆	-	188 - 249	152 - 189	113 - 121	128 - 156	79 - 110	HENDERSON SECONDARY SCHOOL	
HILLGROVE SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆	-	198 - 228	155 - 189	-	120 - 156	64 - 109	HILLGROVE SECONDARY SCHOOL	
HOLY INNOCENTS' HIGH SCHOOL*		☆☆	☆☆	☆☆	-	222 - 243	183 - 197	-	138 - 155	100 - 111	HOLY INNOCENTS' HIGH SCHOOL*	
HONG KAH SECONDARY SCHOOL			☆☆☆☆	☆☆	-	188 - 246	152 - 187	114 - 135	120 - 149	76 - 112	HONG KAH SECONDARY SCHOOL	
HOUGANG SECONDARY SCHOOL			☆☆☆☆	☆☆	-	211 - 235	171 - 191	-	133 - 155	93 - 107	HOUGANG SECONDARY SCHOOL	
HUA YI SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆	-	225 - 247	180 - 199	-	139 - 158	100 - 111	HUA YI SECONDARY SCHOOL	
HWA CHONG INSTITUTION	♫		☆☆☆☆	☆☆	☆☆☆	-	259 - 283	-	-	-	HWA CHONG INSTITUTION	
JUNYUAN SECONDARY SCHOOL			☆☆☆☆	☆☆	-	200 - 229	172 - 199	-	140 - 149	94 - 133	JUNYUAN SECONDARY SCHOOL	
JURONG SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆	-	228 - 252	182 - 198	-	128 - 159	74 - 113	JURONG SECONDARY SCHOOL	
JURONG WEST SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆	-	198 - 226	168 - 192	-	124 - 159	71 - 111	JURONG WEST SECONDARY SCHOOL	
JURONGVILLE SECONDARY SCHOOL			☆☆☆☆	☆☆	-	201 - 228	163 - 190	-	137 - 151	90 - 109	JURONGVILLE SECONDARY SCHOOL	
JU YING SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆	-	188 - 231	152 - 182	113 - 125	121 - 151	61 - 112	JU YING SECONDARY SCHOOL	
KENT RIDGE SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆	-	189 - 241	154 - 198	-	128 - 156	87 - 112	KENT RIDGE SECONDARY SCHOOL	
KRANJI SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆	-	232 - 252	184 - 198	-	145 - 159	105 - 112	KRANJI SECONDARY SCHOOL	
KUO CHUAN PRESBYTERIAN SECONDARY SCHOOL*			☆☆☆☆	☆☆	-	226 - 241	176 - 198	-	-	-	KUO CHUAN PRESBYTERIAN SECONDARY SCHOOL*	
LOYANG SECONDARY SCHOOL			☆☆☆☆	☆☆	-	195 - 221	166 - 192	-	133 - 157	94 - 114	LOYANG SECONDARY SCHOOL	
MACPHERSON SECONDARY SCHOOL		☆☆	☆☆	☆☆	-	188 - 257	152 - 195	114 - 124	132 - 156	62 - 110	MACPHERSON SECONDARY SCHOOL	
MANJUSRI SECONDARY SCHOOL*		☆☆	☆☆☆☆	☆☆	-	201 - 236	160 - 187	-	123 - 151	72 - 107	MANJUSRI SECONDARY SCHOOL*	
MARIS STELLA HIGH SCHOOL*	♫	☆☆	☆☆☆☆	☆☆	★	-	232 - 248	-	-	-	MARIS STELLA HIGH SCHOOL*	
MARSILING SECONDARY SCHOOL			☆☆☆☆	☆☆	-	188 - 239	164 - 187	-	127 - 158	83 - 129	MARSILING SECONDARY SCHOOL	
MAYFLOWER SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆	-	222 - 240	175 - 199	-	134 - 151	92 - 106	MAYFLOWER SECONDARY SCHOOL	
MONTFORT SECONDARY SCHOOL*		☆☆	☆☆☆☆	☆☆	-	208 - 229	170 - 187	-	121 - 151	65 - 119	MONTFORT SECONDARY SCHOOL*	

Appendix 4.1: Primary School Leaving Examination Scores for Public Schools in Singapore (Page 4 of 5)

NAN CHIAU HIGH SCHOOL		☆☆☆	☆☆☆☆☆		-	232 - 252	184 - 199	-	138 - 158	98 - 111	NAN CHIAU HIGH SCHOOL	
NAN HUA HIGH SCHOOL	U	☆	☆☆☆☆☆	☆☆	☆	-	243 - 262	-	-	-	NAN HUA HIGH SCHOOL	
NANYANG GIRLS' HIGH SCHOOL *	🏆		☆☆☆☆☆	☆☆	☆☆☆	-	263 - 287	-	-	-	NANYANG GIRLS' HIGH SCHOOL *	
NATIONAL JUNIOR COLLEGE	🏆		☆☆☆	☆☆	☆☆☆	-	259 - 278	-	-	-	NATIONAL JUNIOR COLLEGE	
NAVAL BASE SECONDARY SCHOOL			☆☆☆			-	188 - 223	158 - 187	133 - 136	121 - 142	72 - 122	NAVAL BASE SECONDARY SCHOOL
NEW TOWN SECONDARY SCHOOL			☆☆☆☆☆	☆☆		-	217 - 236	161 - 195	-	124 - 151	72 - 107	NEW TOWN SECONDARY SCHOOL
NGEE ANN SECONDARY SCHOOL *	U	☆☆	☆☆☆☆☆	☆	☆	-	233 - 259	-	-	151 - 159	111 - 122	NGEE ANN SECONDARY SCHOOL *
NORTH VIEW SECONDARY SCHOOL		☆☆	☆☆☆☆			-	188 - 223	152 - 187	113 - 127	136 - 145	70 - 109	NORTH VIEW SECONDARY SCHOOL
NORTH VISTA SECONDARY SCHOOL		☆☆	☆☆☆☆☆			-	208 - 240	173 - 199	-	134 - 155	94 - 111	NORTH VISTA SECONDARY SCHOOL
NORTHBROOKS SECONDARY SCHOOL			☆☆☆	☆		-	188 - 244	152 - 186	113 - 136	123 - 151	64 - 111	NORTHBROOKS SECONDARY SCHOOL
NORTHLAND SECONDARY SCHOOL			☆☆☆☆			-	188 - 236	152 - 195	113 - 129	115 - 150	63 - 112	NORTHLAND SECONDARY SCHOOL
ORCHID PARK SECONDARY SCHOOL		☆☆	☆☆☆☆☆	☆		-	212 - 236	171 - 196	-	127 - 147	83 - 107	ORCHID PARK SECONDARY SCHOOL
OUTRAM SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆		-	188 - 227	153 - 191	116 - 131	136 - 142	78 - 109	OUTRAM SECONDARY SCHOOL
PASIR RIS CREST SECONDARY SCHOOL		☆☆☆	☆☆☆☆☆	☆		-	222 - 246	182 - 199	-	138 - 154	99 - 121	PASIR RIS CREST SECONDARY SCHOOL
PASIR RIS SECONDARY SCHOOL		☆☆	☆☆☆☆☆	☆☆		-	224 - 265	184 - 197	-	142 - 158	103 - 116	PASIR RIS SECONDARY SCHOOL
PAYA LEBAR METHODIST GIRLS' SCHOOL (SECONDARY) *	U	☆☆☆	☆☆☆☆☆	☆	☆☆	-	-	-	-	133 - 150	94 - 111	PAYA LEBAR METHODIST GIRLS' SCHOOL (SECONDARY) *
PEI HWA SECONDARY SCHOOL		☆☆	☆☆			-	189 - 237	164 - 187	-	127 - 158	88 - 106	PEI HWA SECONDARY SCHOOL
PEICAI SECONDARY SCHOOL		☆☆	☆☆	☆		-	188 - 244	152 - 187	115 - 115	126 - 149	62 - 110	PEICAI SECONDARY SCHOOL
PERCE SECONDARY SCHOOL			☆☆☆☆	☆☆		-	209 - 228	167 - 189	-	-	-	PERCE SECONDARY SCHOOL
PING YI SECONDARY SCHOOL		☆☆	☆☆☆☆☆	☆☆		-	188 - 242	152 - 186	114 - 134	123 - 151	80 - 109	PING YI SECONDARY SCHOOL
PIONEER SECONDARY SCHOOL			☆☆	☆☆		-	188 - 237	154 - 195	121 - 130	122 - 151	68 - 112	PIONEER SECONDARY SCHOOL
PRESBYTERIAN HIGH SCHOOL		☆☆	☆☆☆☆☆	☆☆		-	232 - 248	185 - 199	-	141 - 157	102 - 116	PRESBYTERIAN HIGH SCHOOL
PUNGGOL SECONDARY SCHOOL		☆☆	☆☆☆☆☆			-	188 - 240	152 - 193	113 - 123	103 - 151	69 - 112	PUNGGOL SECONDARY SCHOOL
QUEENSTOWN SECONDARY SCHOOL		☆☆	☆☆☆☆☆			-	212 - 242	164 - 198	-	132 - 150	86 - 113	QUEENSTOWN SECONDARY SCHOOL
QUEENSWAY SECONDARY SCHOOL		☆☆☆	☆☆☆☆☆	☆		-	215 - 244	172 - 197	-	135 - 151	97 - 121	QUEENSWAY SECONDARY SCHOOL
RAFFLES GIRLS' SCHOOL (SECONDARY)	🏆		☆☆☆☆☆	☆	☆☆☆	-	263 - 281	-	-	-	-	RAFFLES GIRLS' SCHOOL (SECONDARY)
RAFFLES INSTITUTION	🏆		☆☆☆☆☆	☆☆	☆☆☆	-	262 - 284	-	-	-	-	RAFFLES INSTITUTION
REGENT SECONDARY SCHOOL			☆☆☆☆			-	188 - 232	164 - 186	-	131 - 158	91 - 105	REGENT SECONDARY SCHOOL
RIVER VALLEY HIGH SCHOOL	🏆		☆☆☆☆☆	☆	☆☆☆	-	254 - 272	-	-	-	-	RIVER VALLEY HIGH SCHOOL
RIVERSIDE SECONDARY SCHOOL	U	☆☆	☆☆☆☆☆	☆☆	☆	-	229 - 254	186 - 199	-	137 - 159	98 - 124	RIVERSIDE SECONDARY SCHOOL
SEMBAWANG SECONDARY SCHOOL		☆☆	☆☆☆☆☆	☆		-	188 - 257	152 - 188	114 - 118	127 - 153	86 - 121	SEMBAWANG SECONDARY SCHOOL
SENG KANG SECONDARY SCHOOL			☆☆☆☆☆	☆		-	203 - 230	173 - 199	-	138 - 150	99 - 105	SENG KANG SECONDARY SCHOOL
SERANGOON GARDEN SECONDARY SCHOOL			☆☆☆☆☆	☆		-	188 - 231	152 - 191	125 - 125	120 - 148	79 - 112	SERANGOON GARDEN SECONDARY SCHOOL
SERANGOON SECONDARY SCHOOL		☆☆	☆☆☆☆☆	☆		-	188 - 232	152 - 184	114 - 114	120 - 153	68 - 126	SERANGOON SECONDARY SCHOOL
SHUQUN SECONDARY SCHOOL		☆☆	☆☆☆☆☆			-	188 - 261	152 - 189	113 - 128	118 - 156	79 - 112	SHUQUN SECONDARY SCHOOL
SILING SECONDARY SCHOOL			☆☆☆	☆☆		-	191 - 231	152 - 180	113 - 123	140 - 150	74 - 93	SILING SECONDARY SCHOOL
SIGLAP SECONDARY SCHOOL			☆☆☆☆☆	☆☆		-	188 - 242	158 - 187	-	126 - 155	74 - 116	SIGLAP SECONDARY SCHOOL
SPRINGFIELD SECONDARY SCHOOL			☆☆☆☆			-	188 - 271	152 - 187	114 - 126	131 - 151	89 - 115	SPRINGFIELD SECONDARY SCHOOL

Appendix 4.1: Primary School Leaving Examination Scores for Public Schools in Singapore (Page 5 of 5)

ST. ANDREW'S SECONDARY SCHOOL*		☆☆	☆☆☆☆☆☆	☆☆		-	236 - 254	190 - 199	-	144 - 159	106 - 111	ST. ANDREW'S SECONDARY SCHOOL*
ST. ANTHONY'S CANOSSIAN SECONDARY SCHOOL*	!	☆☆☆	☆☆☆☆	☆☆	☆	-	227 - 258	191 - 194	-	137 - 153	95 - 107	ST. ANTHONY'S CANOSSIAN SECONDARY SCHOOL*
ST. GABRIEL'S SECONDARY SCHOOL*		☆☆☆	☆☆☆☆	☆☆		-	218 - 246	180 - 198	-	135 - 151	95 - 112	ST. GABRIEL'S SECONDARY SCHOOL*
ST. HILDA'S SECONDARY SCHOOL*	!	☆☆	☆☆☆☆	☆☆	☆	-	230 - 245	186 - 198	-	145 - 156	104 - 111	ST. HILDA'S SECONDARY SCHOOL*
ST. JOSEPH'S INSTITUTION*	!	☆☆	☆☆☆☆	☆☆	☆☆	-	244 - 265	-	-	-	-	ST. JOSEPH'S INSTITUTION*
ST. MARGARET'S SECONDARY SCHOOL*	!	☆☆☆☆	☆☆☆☆	☆☆	☆	-	240 - 252	184 - 199	-	-	-	ST. MARGARET'S SECONDARY SCHOOL*
ST. PATRICK'S SCHOOL*		☆☆	☆☆☆☆	☆☆		-	218 - 234	-	-	142 - 150	105 - 112	ST. PATRICK'S SCHOOL*
SWISS COTTAGE SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆		-	238 - 257	187 - 199	-	146 - 157	107 - 136	SWISS COTTAGE SECONDARY SCHOOL
TAMPINES SECONDARY SCHOOL			☆☆☆☆	☆☆		-	201 - 229	166 - 190	-	130 - 140	90 - 125	TAMPINES SECONDARY SCHOOL
TANGLIN SECONDARY SCHOOL		☆	☆☆☆☆	☆☆		-	188 - 231	152 - 189	115 - 125	144 - 149	76 - 107	TANGLIN SECONDARY SCHOOL
TANJONG KATONG GIRLS' SCHOOL		☆☆	☆☆☆☆	☆☆		-	235 - 271	-	-	-	-	TANJONG KATONG GIRLS' SCHOOL
TANJONG KATONG SECONDARY SCHOOL	!	☆☆	☆☆☆☆	☆☆	☆☆	-	236 - 260	-	-	-	-	TANJONG KATONG SECONDARY SCHOOL
TECK WHYE SECONDARY SCHOOL			☆☆☆☆	☆☆		-	192 - 224	168 - 188	-	135 - 151	92 - 112	TECK WHYE SECONDARY SCHOOL
TELOK KURAU SECONDARY SCHOOL		☆☆	☆☆	☆☆		-	188 - 245	152 - 199	122 - 124	136 - 144	67 - 103	TELOK KURAU SECONDARY SCHOOL
TEMASEK SECONDARY SCHOOL	!	☆☆	☆☆☆☆	☆☆	☆	-	232 - 254	195 - 199	-	145 - 156	106 - 112	TEMASEK SECONDARY SCHOOL
UNITY SECONDARY SCHOOL		☆	☆☆☆☆	☆☆		-	221 - 244	180 - 199	-	144 - 157	105 - 114	UNITY SECONDARY SCHOOL
VICTORIA SCHOOL	!	☆☆	☆☆☆☆	☆☆	☆	-	246 - 270	-	-	-	-	VICTORIA SCHOOL
WEST SPRING SECONDARY SCHOOL			☆☆	☆☆		-	223 - 259	176 - 199	-	131 - 159	91 - 109	WEST SPRING SECONDARY SCHOOL
WESTWOOD SECONDARY SCHOOL		☆	☆☆	☆☆		-	211 - 246	172 - 199	-	136 - 157	68 - 110	WESTWOOD SECONDARY SCHOOL
WHITLEY SECONDARY SCHOOL			☆☆☆☆	☆☆		-	203 - 225	161 - 196	-	122 - 145	75 - 106	WHITLEY SECONDARY SCHOOL
WOODGROVE SECONDARY SCHOOL			☆☆☆☆	☆☆		-	205 - 248	173 - 198	-	121 - 156	79 - 118	WOODGROVE SECONDARY SCHOOL
WOODLANDS RING SECONDARY SCHOOL		☆☆	☆☆☆☆	☆☆		-	216 - 250	175 - 197	-	127 - 157	87 - 122	WOODLANDS RING SECONDARY SCHOOL
WOODLANDS SECONDARY SCHOOL			☆☆☆☆	☆☆		-	188 - 232	164 - 196	-	133 - 155	94 - 112	WOODLANDS SECONDARY SCHOOL
XINMIN SECONDARY SCHOOL	!	☆☆	☆☆☆☆	☆☆	☆☆	-	242 - 263	188 - 199	-	146 - 159	108 - 113	XINMIN SECONDARY SCHOOL
YIO CHU KANG SECONDARY SCHOOL			☆☆☆☆	☆☆		-	188 - 230	152 - 189	118 - 118	124 - 149	82 - 104	YIO CHU KANG SECONDARY SCHOOL
YISHUN SECONDARY SCHOOL			☆☆☆☆	☆☆		-	207 - 246	172 - 199	-	125 - 156	82 - 110	YISHUN SECONDARY SCHOOL
YISHUN TOWN SECONDARY SCHOOL	!	☆☆☆☆	☆☆☆☆	☆☆	☆	-	237 - 261	188 - 199	-	141 - 158	101 - 117	YISHUN TOWN SECONDARY SCHOOL
YUAN CHING SECONDARY SCHOOL			☆☆☆☆	☆☆		-	215 - 239	172 - 196	-	134 - 159	92 - 109	YUAN CHING SECONDARY SCHOOL
YUHUA SECONDARY SCHOOL		☆	☆☆☆☆	☆☆		-	197 - 224	156 - 196	135 - 135	129 - 151	90 - 126	YUHUA SECONDARY SCHOOL
YUSOF ISHAK SECONDARY SCHOOL			☆☆☆☆	☆☆		-	188 - 245	153 - 188	119 - 119	115 - 147	64 - 106	YUSOF ISHAK SECONDARY SCHOOL
YUYING SECONDARY SCHOOL		☆	☆☆☆☆	☆☆		-	188 - 231	158 - 191	-	124 - 151	67 - 106	YUYING SECONDARY SCHOOL
ZHENGHUA SECONDARY SCHOOL			☆☆☆☆	☆☆		-	210 - 241	175 - 199	-	124 - 159	83 - 111	ZHENGHUA SECONDARY SCHOOL
ZHONGHUA SECONDARY SCHOOL	!	☆☆☆	☆☆☆☆	☆☆	☆	-	238 - 257	187 - 199	-	141 - 151	102 - 112	ZHONGHUA SECONDARY SCHOOL

* click on school name to view PSLE scores for affiliate

Appendix 5.1: Informed Voluntary Participation Form

**CONSENT TO PARTICIPATE IN A RESEARCH STUDY:
"USING ICT AS AN ARTEFACT TO IMPROVE STUDENTS' UNDERSTANDING OF PHYSICS CONCEPTS
THROUGH CO-CONSTRUCTION AND PRESCRIPTIVE TUTORING"**

[] I understand that the purpose of this study is to explore whether the learning programme designed and implemented by Benson Soong (a PhD candidate at Cambridge University) is helpful in my Physics revision for the "O" level examinations.

[] I understand that being involved in this research means that I would spend about 2.5 hours each week on the learning programme, which will be conducted both in the school computer lab, as well as the classroom. There are also some interviews, group discussions and surveys (as well as the school tests) that I would take part in, in order to evaluate Benson's learning programme.

[] I understand that all information which might link me to my interviews, discussions, or survey data, as well as test results, will be kept confidential. Only false names will be used and no one will be able to associate my name with my data.

[] I understand that I am free to choose whether to participate in this study or not. If I do participate, I am free to withdraw at any time. If I withdraw from this study, all my data will be purged from the study. There are also no negative repercussions or consequences should I not take part, or withdraw, from this study.

[] I expect that I will experience a minimum of risk, discomfort or stress while participating in this study. However, if during any point in the study I feel uncomfortable, I may simply stop participating or seek help from any school teacher.

[] I understand that while the learning programme has been designed to help me revise Physics better (thereby leading to improvements in my results), there can be no guarantee of its effectiveness.

[] I understand that if my guardians/parents have further questions about the research itself, I (or my guardians/parents) may contact Benson in person at Bartley Secondary School, or via his mobile number at 9767 7349, or his email at bmhs2@cam.ac.uk. I may also contact his Supervisor, Professor Neil Mercer at the Faculty of Education of Cambridge University via his email at nmm31@cam.ac.uk.

[] I have read and understood this form completely and have decided that I will participate in Benson's study. My signature indicates my consent to participate.

Participant Name: _____ Participant Signature: _____

Researcher Name: Benson Soong Researcher Signature: _____

Date: _____

Appendix 5.2: Initial Survey Form (Page 1 of 2)

Initial Survey Form								
Name: _____			Class Index Number: _____			Date: _____		
Based on my Secondary 3 results so far, my current average Physics grade is:								
A1	A2	B3	B4	C5	C6	D7	E8	F9
[]	[]	[]	[]	[]	[]	[]	[]	[]
For my Secondary 3 final physics exams, I think I will be able to score:								
A1	A2	B3	B4	C5	C6	D7	E8	F9
[]	[]	[]	[]	[]	[]	[]	[]	[]
For my Secondary 4 mid-term exam, I think I will be able to score:								
A1	A2	B3	B4	C5	C6	D7	E8	F9
[]	[]	[]	[]	[]	[]	[]	[]	[]
For my prelims (in Secondary 4), I think I will be able to score:								
A1	A2	B3	B4	C5	C6	D7	E8	F9
[]	[]	[]	[]	[]	[]	[]	[]	[]
For my "O" levels, I think I will be able to score:								
A1	A2	B3	B4	C5	C6	D7	E8	F9
[]	[]	[]	[]	[]	[]	[]	[]	[]
I _____ learning Physics								
(1) very much like (2) like (3) have no special liking or disliking for (4) dislike (5) very dislike								
I think that group work is _____ for learning Physics								
(1) very important (2) important (3) neither important or unimportant (4) unimportant (5) very unimportant								
My method of Physics revision is currently (ranking from 1 to 7, using "9" as an indication that you hardly use this revision method):								
[] Memorising facts and formulas from the textbook								
[] Memorising answers from 10-year series and/or past exam questions								
[] Working together with my classmates in order to learn how to solve Physics problems								
[] Reading and re-reading the textbook or other guide books								
[] Working out problems from 10-year series and/or past exam questions in order to practice, and not to memorise								
[] Asking my school teachers for help								
[] Asking my private tutor or knowledgeable friend/family member for help								
These are the other methods I commonly employ when revising Physics:								
>								

Appendix 5.2: Initial Survey Form (Page 2 of 2)

I _____ using the computer

(1) like (2) neither like or dislike (3) dislike

I currently _____ a private physics tutor (e.g. tuition teacher)

(1) have (2) do not have

I think I know _____ of my own Physics misconceptions/misunderstandings.

(1) almost all (2) a lot (3) quite a lot (4) a few (5) very little

I think my school teacher knows _____ of my Physics misconceptions/misunderstandings.

(1) almost all (2) a lot (3) quite a lot (4) a few (5) very little

I think my private tutor knows _____ of my Physics misconceptions/misunderstandings.

(1) almost all (2) a lot (3) quite a lot (4) a few (5) very little

My other comments are:

Appendix 5.3: Sample of Student Handout During CMCPs

USING ICT AS AN ARTEFACT TO IMPROVE STUDENTS' UNDERSTANDING OF PHYSICS CONCEPTS THROUGH CO-CONSTRUCTION AND PRESCRIPTIVE TUTORING: PILOT STUDY 1, SESSION 1

Name/Nickname: _____ Date: 28 Oct 2008

Ground Rules:

A key objective of getting you to work with your partner(s) through the computer is so that we may see your thought processes when you and your partner(s) are solving the questions that we posed. When we have insights into your thought processes, we would be able to uncover your Physics misconceptions or misunderstandings, thereby allowing us to specifically target your weaker areas. Hence, it is important that you have a good working relationship with your partner. To help you establish a good working relationship with your partner(s), here are the ground rules:

The basic ground rules for "chatting" online are:

- You agree to share your ideas and listen to each other, no matter how silly it might appear
- You agree to consider what your partner(s) has written or drawn
- You agree to respect each other's opinions
- You agree to give reasons for your ideas
- You agree to express your ideas and workings neatly and clearly
- If you disagree, you will ask "why?" or provide reasons for your disagreement
- You agree not to discuss any topic that is not related, including asking your partner who he/she is
- You agree to only work on solving the problems (e.g. no web-surfing!)
- You will try to agree on a solution in the end, prior to asking the teacher to check your answer

Questions:

1a) What is the difference between a vector and a scalar?

1b) Which of the following are scalars and which are vectors?

- Velocity, Speed, Distance, Displacement, Time, Temperature, Force, Mass, Acceleration

2) An old man, starting his walk from Point O, took 1 minute to travel 3 metres North. From there, he took another 4 minutes to travel 4 metres East. Draw and label a diagram of his walk and then calculate his speed and velocity.

3a) A small airplane was trying to take off a runway when the pilot saw an object some distance from the runway, and decided to step on the brakes. The airplane had a total mass of 2000kg and was travelling at a speed of 150km/hr. If the object was 300 metres away from the airplane when the pilot saw it, and the maximum braking force of the airplane is 6000N, could the airplane stop in time?

3b) Assuming the pilot used the maximum braking force, how far did the plane travel before it stopped?

Survey Questions: (to be completed and submitted only after the session)

* Initially, I thought that the questions were:

Very Easy Easy Neither Easy nor Difficult Difficult Very Difficult

* After trying to answer the questions together with my partner, I found that the questions were:


Very Easy Easy Neither Easy nor Difficult Difficult Very Difficult

* How do you feel about working with a partner via the computer to solve Physics questions?

Very Comfortable Comfortable Neutral Uncomfortable Very Uncomfortable

* Other comments:

Appendix 5.4: Sample of 'Notes' Handout During PT (Page 1 of 15)



Physics Revision Lessons for the “O” Levels Pilot Study Prescriptive Tutoring 1

29 Oct 08
Benson Soong
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> What is “Prescriptive Tutoring”?

- It is when we look at **your thought processes**, and then assist you by **directly treating your misunderstandings** or misconceptions
- You must not be shy...only by exposing your misunderstanding will you learn better!

Appendix 5.4: Sample of 'Notes' Handout During PT (Page 2 of 15)

*Take note that these are PowerPoint slides, and the 'boxes', 'arrows' and any remedial instructions or comments (usually next to the 'arrows') only appear when the mouse button is clicked. Hence, students always get to review what they have written, with dialogic discourse taking place *before* the remedial instructions or comments are shown.

Question 1a: What is the difference between a vector and a scalar?

Tata	lets start with qn 1 now
Fefe	ok
Tata	vector-got direction and magnitude but scalar only direction agree?
Fefe	ya
Fefe	so settled ?
Tata	ok so for qn 1 ans is vector-got direction and magnitude but scalar vector-got direction and magnitude but scalar only direction .
Tata	ok??
Fefe	vector - magnitude + direction , scalar - direction

Reveals a lack of revision – definitions must be remembered!

Wewa	scalar is sth which has magnitude n direction
Cece	i think it is vector that has magnitude and direction
Wewa	u sure ah?
Cece	i dont knpw
Cece	the difference is that one got direction and the other one dont have
Wewa	that one i noe
Wewa	but i don noe which one

Question 1a: What is the difference between a vector and a scalar?

- What is the difference between a vector and a scalar?

Bibi	1a) the differences is vector has direction but scalar has no direction
Ziki	yup

This is the ½ mark answer – one important component is missing

Wewa	vector involve direction
Wewa	scalar does not involve direction
Cece	hey the answer is correct which is the difference is one got directoin and the other dont have

Appendix 5.4: Sample of 'Notes' Handout During PT (Page 3 of 15)

Question 1a: What is the difference between a vector and a scalar? Answer

Tata	arghh wrong maybe the phrasing part
Tata	hey scalar is magnitude no direction
Tata	!!!
Fefe	oh ya
Tata	vector-direction and magnitude, scalar-magnitude

Correct! The two components are magnitude and direction.

Joi & Didi:

Vector	Scalar
Value with direction	Value with No direction

Question 1b: Which of the following are scalars and which are vectors? Answer

- Velocity, Speed, Distance, Displacement, Time, Temperature, Force, Mass, Acceleration

Mostly no problems:

Bibi	1b) scalar : speed, distance time temperature mass and vector : velocity displacement force and acceleration.
Ziki	okay

BUT...this is worth discussing:

Wewa	if vector, needs direction right
Cece	i mean acceleration got increasing and decreasing so ,isnt it directon?
Wewa	temperature also have increasing n decreasing
Cece	acceleration is vector right ?
Wewa	ya it is
Cece	so there is no directoin in acceleration
Wewa	but vector must hav direction
Cece	ya
Wewa	that means acceleration also hav direction

Appendix 5.4: Sample of 'Notes' Handout During PT (Page 4 of 15)


Scalars & Vectors Review

- Scalars are quantities (something you measure) that have magnitude (size) but NOT direction
 - E.g. Mass of 100kg, temperature of -10°C
 - Increase/decrease is NOT DIRECTION
- Vectors are quantities that have both magnitude AND direction
 - E.g. A downwards force of 10N, acceleration of 2m/s^2 from A to B
- Scalar – Speed || Vector – Velocity
- Question: Why do we sometimes say that “the velocity of the car is 5m/s?” or “The force of the object is 5N”?

Question 2

- An old man, starting his walk from Point O, took 1 minute to travel 3 metres North. From there, he took another 4 minutes to travel 4 metres East. Draw and label a diagram of his walk and then calculate his speed and velocity.

Tata _	i dont think velocity got formulas
Tata _	*formula
Fefe _	then how to caculate?
Tata _	hmm...mayb same as speed



 You just said that velocity and speed are different!
 This reveals a lack of conceptual understanding...

Joji _	Speed and velocity the same right?
Didi _	o
Joji _	i mean.. ho to find velocity

Appendix 5.4: Sample of 'Notes' Handout During PT (Page 5 of 15)

Question 2

■ An old man, starting his walk from Point O, took 1 minute to travel 3 metres North. From there, he took another 4 minutes to travel 4 metres East. Draw and label a diagram of his walk and then calculate his speed and velocity.

Joji _	velocity have to be in terms of the unit (m/min) i thought?
Joji _	SI units.
Joji _	mins change to s
Didi _	ok...
Joji _	m change to KM
Didi _	u sure?

Always give your answers in SI units, as calculations must be done in SI units!

Bibi _	then the speed is 7m divide by (5min multiplied by 60s)
Ziki _	wrong
Bibi _	then
Ziki _	maybe just 1.4m/min?

Question 2

■ An old man, starting his walk from Point O, took 1 minute to travel 3 metres North. From there, he took another 4 minutes to travel 4 metres East. Draw and label a diagram of his walk and then calculate his speed and velocity.

Tata _	speed=(4+3)m/(4+1)min=7m/(5x60)s=84m/s
Tata _	velocity how??
Fefe _	why 5 over 60 sec?
Tata _	eh...no
Tata _	is 5/3600
Tata _	ok lets recal.
Fefe _	not 3600s
Fefe _	ok 1 min = 60 secs
Fefe _	so 5 min is 300secs

Careless?

Appendix 5.4: Sample of 'Notes' Handout During PT (Page 6 of 15)

Question 2

■ An old man, starting his walk from Point O, took 1 minute to travel 3 metres North. From there, he took another 4 minutes to travel 4 metres East. Draw and label a diagram of his walk and then calculate his speed and velocity.

Tata	velocity is displacement /time
Fefe	so same as speed?
Fefe	i don think so leh
Fefe	not sure
Tata	mayb need direction??
Fefe	um
Fefe	i don think can calculate direction
Tata	so is the same
Tata	??
Fefe	try
Tata	so velocity=displacement /time=7m/300s=0.0233m/s
Fefe	ok

Confusion between displacement and distance

Question 2

■ An old man, starting his walk from Point O, took 1 minute to travel 3 metres North. From there, he took another 4 minutes to travel 4 metres East. Draw and label a diagram of his walk and then calculate his speed and velocity.

Bibi	speed 0.0233m/s
Ziki	yup
Bibi	ok then how to find velocity
Ziki	i think is 5 divide 60
Ziki	0.083333333333333 0.08333m/s
Ziki	wrong.
Ziki	time change is 3mins
Ziki	so is 0.0278m/s
Ziki	wrong again
Bibi	hey ur velocity is wrong but speed is correct
Bibi	i think is 4m-3m=1m
Bibi	1 divide with (5min multiplied with 60s)
Bibi	3.33m/s velocity
Ziki	correct?
Bibi	not correct
Bibi	isnt 3min
Bibi	5.55m/s
Ziki	how?
Ziki	how you get
Bibi	i take 4-3
Ziki	what's 4??
Bibi	1m divide by 3min multiplied by 60s
Bibi	hey im not sure how to find velocity
Ziki	i dont know i think displacement is 5 and time changed is
Bibi	ok try
Bibi	5 divide by 3 multiplied 60s
Bibi	0.0278m/s
Bibi	you get .?
Ziki	the teacher said wrong.i dun why
Bibi	isnt velocity is change direction rite
Bibi	so i think 4m divide by 4min multiply by 60s
Bibi	0.167m/s
Ziki	it is the displacement divide the time changed
Bibi	ok let try
Bibi	no my ans wrong
Ziki	why?
Bibi	don noe i think we should take 4m divide by change of time
Bibi	leuz 4m is the direction change

This reveals a lack of conceptual understanding in what is displacement and time taken (quite common actually)

Appendix 5.4: Sample of 'Notes' Handout During PT (Page 7 of 15)

Question 2 Answer

- An old man, starting his walk from Point O, took 1 minute to travel 3 metres North. From there, he took another 4 minutes to travel 4 metres East. Draw and label a diagram of his walk and then calculate his speed and velocity.

by pythagoras theorem
 distance of the black line = root of (9 + 16)
 = root of 25
 = 5m

Therefore: $\text{Velocity} = \frac{\text{Total Displacement}}{\text{Total time}}$

= 5m / 5 min
 = 5m / 300s
 = 1/60
 = 0.01666666666666667
 = 0.0167 m/s (3 S.F.)

No one stated the DIRECTION of the velocity!
From O to A

Distance & Displacement Review

- Speed = Total Distance Travelled / Total Time Taken
- Velocity = Displacement / Total Time Taken
- Total Time Taken = ALL the time taken
- Total Distance Travelled = All distance travelled in order to get from Point A to Point B
- Displacement = Shortest distance from Point A to Point B
 - Therefore, for velocity, always mention the direction (e.g. from Point A to Point B)

Appendix 5.4: Sample of 'Notes' Handout During PT (Page 8 of 15)



Review Questions

- Review Question 1: A car travelled Southwards, taking 2 minutes to travel 100 metres. It then travelled Westwards, taking 1 minute to travel 100 metres. What is the distance travelled? What is the displacement?
- Review Question 2: If I ran round a track of diameter 100m in 10 seconds, starting from Point O and ending at the same point, what is my average speed and velocity?
- Group Discussion:
 - Using RQ2 as a base, offer other questions we can ask about speed and velocity...
 - When would an object's average speed and velocity be EXACTLY the same?



Question 3a

- A small airplane was trying to take off a runway when the pilot saw an object some distance from the runway, and decided to step on the brakes. The airplane had a total mass of 2000kg and was travelling at a speed of 150km/hr. If the object was 300 metres away from the airplane when the pilot saw it, and the maximum braking force of the airplane is 6000N, could the airplane stop in time?

No one except one group got this question correct...

Appendix 5.4: Sample of 'Notes' Handout During PT (Page 9 of 15)

Question 3a

■ A small airplane was trying to take off a runway when the pilot saw an object some distance from the runway, and decided to step on the brakes. The airplane had a total mass of 2000kg and was travelling at a speed of 150km/hr. If the object was 300 metres away from the airplane when the pilot saw it, and the maximum braking force of the airplane is 6000N, could the airplane stop in time?

Wewa	means mus do F-f= ma
Wewa	?
Wewa	is it 150 X (300/1000)?
Cece	so that is that ?
Wewa	no
Cece	what is that?
Wewa	actually i also don noe
Wewa	its wrong
Cece	F-f=ma
Wewa	use that ?
Cece	2000(10)-6000=ma
Cece	14000=ma
Wewa	mass is 2000
Cece	14000=2000(a)
Wewa	then find acceleration?
Cece	a=7

$F = MA$
 $-6000N = 2000a$
 $a = -3$

Force is a vector, so direction must be taken into account!

Question 3a

■ A small airplane was trying to take off a runway when the pilot saw an object some distance from the runway, and decided to step on the brakes. The airplane had a total mass of 2000kg and was travelling at a speed of 150km/hr. If the object was 300 metres away from the airplane when the pilot saw it, and the maximum braking force of the airplane is 6000N, could the airplane stop in time?

Wewa	$T = D/S = 0.3/150 = 0.002$
Cece	0.3 where do get thjs one?
Wewa	300/1000
Wewa	firm meters to km
Wewa	$a = v-u/t = 0-150/0.002 = -75000 \text{ m/s}^2$

Must use SI units for calculation!

Appendix 5.4: Sample of 'Notes' Handout During PT (Page 10 of 15)

Question 3a

■ A small airplane was trying to take off a runway when the pilot saw an object some distance from the runway, and decided to step on the brakes. The airplane had a total mass of 2000kg and was travelling at a speed of 150km/hr. If the object was 300 metres away from the airplane when the pilot saw it, and the maximum braking force of the airplane is 6000N, could the airplane stop in time?

Didi _	1 second can travel 150000/60
Didi _	1 second can teavel 2500 metre

Be careful when converting!

Question 3a

■ A small airplane was trying to take off a runway when the pilot saw an object some distance from the runway, and decided to step on the brakes. The airplane had a total mass of 2000kg and was travelling at a speed of 150km/hr. If the object was 300 metres away from the airplane when the pilot saw it, and the maximum braking force of the airplane is 6000N, could the airplane stop in time?

Joji _	what is the unit of acceleration
Joji _	i mean in this case
Joji _	km/h?
Didi _	m/s
Didi _	square
Joji _	oi
Joji _	its 6000 dive by 2000 la
Didi _	ans is 3
Joji _	F = M A a= F/M

Weak unit analysis!

The units for acceleration MUST always be m/s²

Appendix 5.4: Sample of 'Notes' Handout During PT (Page 11 of 15)

Question 3a

- A small airplane was trying to take off a runway when the pilot saw an object some distance from the runway, and decided to step on the brakes. The airplane had a total mass of 2000kg and was travelling at a speed of 150km/hr. If the object was 300 metres away from the airplane when the pilot saw it, and the maximum braking force of the airplane is 6000N, could the airplane stop in time?

Joji _	see how long did it brake
Joji _	-50
Didi _	hallo
Didi _	sth is wrong
Didi _	negative time?
Joji _	its deceleration, so negative value is expected
Didi _	ya
Joji _	acceleration when negative = deceleration so dun be so shock..

Negative time???
No it's not! Acceleration when negative can also mean acceleration is in the opposite DIRECTION

Question 3a

- A small airplane was trying to take off a runway when the pilot saw an object some distance from the runway, and decided to step on the brakes. The airplane had a total mass of 2000kg and was travelling at a speed of 150km/hr. If the object was 300 metres away from the airplane when the pilot saw it, and the maximum braking force of the airplane is 6000N, could the airplane stop in time?

Joji _	u agree braking = decelerate?
Didi _	Yap
Didi _	thats wat i am talking abt
Joji _	so if decelerate isnt the acceleration be negative?
Didi _	Yap
Didi _	braking force is deceleration
Joji _	assume that time for braking is 50
Didi _	so is -6000N
Joji _	NEWTON WHERE GOT NEGATIVE?
Joji _	a = 3
Joji _	no negative
Didi _	cher
Joji _	but because its its decelerating..... thats why i put negative at my 2nd working
Didi _	say dorection have negative

Acceleration when negative can also mean acceleration is in the opposite DIRECTION.

Force has a NEGATIVE value if it is acting in the OPPOSITE DIRECTION

Appendix 5.4: Sample of 'Notes' Handout During PT (Page 12 of 15)



Question 3a Answer: Method 1

- A small airplane was trying to take off a runway when the pilot saw an object some distance from the runway, and decided to step on the brakes. The airplane had a total mass of 2000kg and was travelling at a speed of 150km/hr. If the object was 300 metres away from the airplane when the pilot saw it, and the maximum braking force of the airplane is 6000N, could the airplane stop in time?

Joji _	no .. the question asking... if the airplane can stop in time
Didi _	speed given
Didi _	150km=150,000m
Didi _	so
Joji _	I KNOW!
Joji _	DRAW VELOCITY TIME GRAPH@@@@@@@@@@@@@2

This is actually correct...but how to do it?



Question 3a Answer: Method 2

- A small airplane was trying to take off a runway when the pilot saw an object some distance from the runway, and decided to step on the brakes. The airplane had a total mass of 2000kg and was travelling at a speed of 150km/hr. If the object was 300 metres away from the airplane when the pilot saw it, and the maximum braking force of the airplane is 6000N, could the airplane stop in time?

- *What values did the question give?*
- *What topic would this question be from?*



Kinematics Review

- Deceleration means that acceleration is slowing down
- Negative acceleration means that acceleration is in the opposite direction of the object's current motion
- Force has a negative value when it is in the opposite direction of the object's movement
- Always ensure SI units!
- Always check your units!
- Review Question:
 - A car weighting 1000N was initially travelling at 100km/hr. If it stops after a distance of 100m, how long did the car take to stop?



Question 3b

- Assuming the pilot used the maximum braking force, how far did the plane travel before it stopped?

*No one got this question correct,
and only 1 group attempted it...*



Question 3b Answer

- Assuming the pilot used the maximum braking force, how far did the plane travel before it stopped?

- *What is the formula for KE?*
- *What is the formula for PE?*
- *What is the formula for Work Done?*
- *What are their SI units?*



W.E.P. Review

- $KE = \text{Kinetic Energy} = \frac{1}{2} mv^2 \text{ J}$
- $PE = \text{Potential Energy} = mgh \text{ J}$
- $Wd = \text{Work Done} = Fd \text{ J}$
- Based on the law of conservation of energy, total KE and PE are conserved in an isolated system. Hence, **Wd could be** equivalent to KE or PE for calculation purposes!
- Review Question: A small car with a mass of 100kg was moving up a steep hill with a vertical height of 5m. The car had an initial velocity of 36km/hr and if it comes to rest at the top of the hill,
 - What is its KE at the bottom of the hill?
 - What is its PE at the top of the hill?
 - How much work was done by moving it to the top of the hill?

Appendix 5.4: Sample of 'Notes' Handout During PT (Page 15 of 15)



Final Comments

- Don't waste too much time drawing nice diagrams... square blocks will do!
- Need a better problem solving strategy! All questions are meant to be solvable!
 - For now, try to see if you tell which topic the question is asking about, then start by writing out the formulas you know, and then seeing how to "fill in the gaps"
- Don't use your own "theory" – use the concepts learnt!
- If the units are the same (e.g. Joules for KE, PE, Wd), then there is a good chance that you can use one to find the other!

Appendix 6.1: Original Questions Posed to Ms Er (in order to get her reflections)

Benson Soong
To: Er Siew Shin;
15/8/2009 11:1

Thoughts and Reflections on PT

Hi Siew Shin,

As spoken, I was wondering if I could get your thoughts and reflections on the prescriptive tutoring sessions that we have been conducting since the start of the year.

Broadly, I would like if you could address these three main themes:

Theme 1: PT as a means of obtaining deeper insights into your students' minds.

- 1) Did PT help you obtain deeper insights into your students' minds, especially compared with traditional revision methods? If applicable, please provide examples. (e.g. how does reading students' logs differ from marking their worksheets).
- 2) From an effectiveness perspective, was PT effective in uncovering students' thought processes and knowledge base? If applicable, please provide examples. (e.g. PT would be considered effective if it helped you uncover interesting and never seen before misconceptions, or if it revealed to you certain student characteristics that you have not observed before).
- 3) From an efficiency perspective, was PT efficient in uncovering students' thought processes and knowledge base? If applicable, please provide examples. (e.g. PT would be considered efficient if, given the time and effort to read the logs and prepare the materials to address students' misconceptions/misunderstanding, other forms of intervention that addressed the same or similar space would require more amount of time).

Theme 2: PT as a means of informing teaching practices.

- 1) As a result of reading the students' collaborative problem-solving logs and preparing to address their misunderstandings/misconceptions, did PT inform your teaching practice? If applicable, please provide examples. (e.g. due to PT, did you consider that for future classes, certain topics should be taught differently).
- 2) Do you think that the practice of PT could influence how teachers teach and/or revise physics concepts? If applicable, please provide examples. (e.g. for example, I notice that our classroom revision classes had much more dialog with the students as compared to the revision class Robin provided to 3E1 (in fact, we addressed the same topic on heat transfer. For our session, we talked mostly about how students thought about the concepts and discussed why their conceptions (e.g. temperature is due to kinetic movement of the molecules, and not collision between molecules) were inaccurate, but Robin's session was focused on MCQ questions and why the answers were correct. In a way, Robin's class was much more disciplined and not filled with random questions -- all the questions were on-task!).
- 3) Would you encourage your teachers to try PT? Do you think PT would outlive my presence in school? If applicable, please provide examples. (e.g. for example, perhaps you can talk about the TLLM Ignite application, and how Minyin is trying it out for Chemistry).

Theme 3: PT as a practical revision method.

- 1) Do you think that at present, even without my presence and assistance, PT is still do-able in school? If applicable, please provide examples. (e.g. How was your experience doing PT with the 3E1 class, and how is your take on Minyin's experience?)
- 2) Do you think that PT is implementation in most (if not all) public secondary science classrooms? Why?
- 3) If given the start of a new year and a new Secondary 3 class which you are meant to teach until they take their 'O' levels, how would you integrate PT into your curriculum?

Do feel free to anything else you'd like to add. Thanks!

~Benson

Appendix 6.2: Ms Er's Response to Reflection Questions Posed (not used in the dissertation; Page 1 of 3)

General Thought on PT

In my opinion, reading students' collaborative problem-solving logs is a meaningful, enlightening, if not a transformative experience/process.

If I recall what I have learnt from my training as a teacher at NIE, I have been taught the typical elements of good classroom teaching – knowing students prior knowledge, use of “hooks” to get students attention, building new concepts via the linking to previous knowledge, proper sequencing, assessment to further inform revision, etc. As I strive to become a competent teacher, I have used various strategies to understand students' preconceptions/misconceptions to better inform my teaching practice. These included marking homework, professional discourse with fellow colleagues, reading the markers' report and relevant materials/books, or classroom discussions to gain insights into what and how students think. However, the amount of knowledge gleaned (mostly generic in nature) in my 5yrs of teaching experience is much less than the insights that I gained through 1 yr of PT. These insights can be broadly classified into two categories:

- (1) Their preconceptions about Physics knowledge
- (2) Their learning difficulties (other than misconceptions) e.g language, inability to comprehend the question, etc

Empowered with knowledge of the above, reading students' log has been meaningful in enabling me to better connect with my students' learning needs. It has fostered a collegial and positive learning climate where there is a greater and richer exchange of knowledge and concepts between me and my students. I noticed a greater confidence level in many students and the enthusiasm and perseverance to arrive at the correct answer “using sound physics concepts/ideas”. PT has allowed for a “thinking” culture to evolve, an important skill that will help prepare my students for the demands of education at the next level. Watching how my students are propelled to the next level (=depth) of learning, the interest generated in Physics, as well as witnessing this intellectual growth in my students; it has further increased my satisfaction and fulfillment as a teacher, beyond the academic aspects.

Theme 1: PT as a means of obtaining deeper insights into your students' minds

There is no doubt in PT as a effective tool in obtaining deeper insights into my students minds. Traditional revision methods, such as marking of assignments and assessment papers, discussion of difficult problems, “thinking aloud” process by the teacher on the whiteboard usually rely on the experiences accumulated to “guess” students' preconceptions, level of conceptual attainment as well as the conceptual misconceptions.

Reading students' logs removes the need to “guess” students' thinking process and their knowledge base. From this point of view, PT is definitely effective.

Reading the logs allows me to identify and understand their struggle with certain concepts/ideas, the obstacles that prevent them from arriving at the correct answer, and alternative ways of explanation that is more acceptable in their lingo.

Examples

- *Temperature is related to the kinetic energy of the molecules, hence the speed, not the collision between molecules*
- *EM Induction (or Flemings RH rule) can only be applied to magnetic materials/object. Hence if an aluminium aeroplane is flying across a magnetic field, an induced emf cannot be produced (incorrect)*
- *Language interpretation e.g number of turns halved meant $\frac{1}{2}$ revolution (from students' point of view)*
- *Models, such as the “MacDonald” analogy can be useful in helping student to better differentiate between current and potential difference. Students mistakenly think that current is used up (as opposed to “energy” being used up) in a circuit.*

Appendix 6.2: Ms Er's Response to Reflection Questions Posed (not used in the dissertation; Page 2 of 3)

Theme 2: PT as a means of informing teaching practices

- (1) Yes – PT has definitely informed my teaching practice. E.g Topic on “Magnetism” should be taught differently. My focus in the Magnetism Unit has been to go through the factual content, such as laws/properties of magnetism, induced magnetism and focus more on Electromagnetism and EM Induction. However, I realized that the fundamentals of Magnetism is important and I cannot assume that all students have learnt about Magnetism in Primary schools (e.g the foreigners who did not go thru the Primary school). For example, the compass could be dealt with deeper investigation to impress upon students the function of the compass and the magnetic properties of the compass needle.
- (2) The practice of PT can influence how teachers teach and revise physics concepts. I noticed a greater amount of dialogue taking place in my classroom while at the same time, being able to cater to the learning needs for a greater number of students. With better insights into how students are thinking (as gathered from reading their chat-logs), I find that I am progressively thinking and planning from students' mental model and responding to how they are thinking about the physics concepts and ideas. It also injects expands and inspires the development of new ideas/ways on how to bring across certain models and ideas. 3 examples serves to illustrate this:
 - a. Circuit model – how electrons serve as a carrier of energy, that electrons do not get “eaten up” by the component but instead the energy is passed to the component; how electrons can split into 2 paths yet carrying the same amount of energy (pd in parallel same but current splits up). Analogy can be drawn to the MacDonalds delivery man. It also surfaces the struggle of what determines brightness – the voltage, or current.
 - b. Kinetic Model – the struggle with the abstract knowledge of how temperature is related to speed of molecules (hence the Kinetic Energy) and how the change of state is related to the separation between the molecules (hence the Potential Energy), how pressure changes is related to the number of collisions (hence size of force) on the surfaces of the container. Before, these ideas were not discussed adequately in class (I left it to the Chemistry teachers and only focused on the Brownian Motion) but the PT sessions have highlighted the importance and the relevance to discuss this with my 3E1 class. Knowledge is now better organized with questions better selected and sequenced to progress students' conceptual layers in the Kinetic Model chapter.
 - c. Waves – how shallow ends will result in slower speeds and hence shorter wavelengths (provided frequency remains constant). Before, I got students to memorize by imagining how speed of water changes as it approaches the shore. However, an alternative method would be that the friction at shallower ends simply slows down the wave – this seems to appeal and help most students to remember better.
- (3) Personally, I would encourage some teachers to try PT.
I see the following obstacles:
 - Reading the logs is a skill that needs to be shown or practiced
 - How to discuss and address misconceptions in a class when the teacher does not feel competent with regards to the topic or concept
 - Time is a big obstacle. The computer lab session takes 2hrs. Reading the logs take a minimum of 2 hrs to digest and consolidate students' thoughts and areas of misconceptions. Reflecting on “why” students think this way, “how” to address with convincing alternatives and “what” should follow to ensure students overcome the misconception and move on to the normative view; this takes another 1-2 hours. Preparation of the relevant materials (e.g extracting of relevant sections of the chat logs, categorizing of concepts, practice qns to follow) takes another 1-2 hrs. Its humanely impossible to do it for more than one class (8hrs of PT process vs 2hrs of assignment marking, assuming that it takes the same amount of time to prepare the questions) per week. Given the administrative burden, other teaching-related work such as setting of test/exam papers, preparation of teaching materials, CCA/CCD commitment, meetings, etc,

Appendix 6.2: Ms Er's Response to Reflection Questions Posed (not used in the dissertation; Page 3 of 3)

I feel that not all teachers may be willing to invest the personal time to do the PT cycle initially or even for long periods of time.

- Teaching is a personal style and the adoption of techniques and strategies varies among individuals. Against the backdrop of tight curriculum time and the use of ICT, some teachers may not feel comfortable.
- For PT to outlive your presence in the school and be sustained over a period of time, a human driver is required. Support structures need to be set in place to coax and convince other teachers on board.

Theme 3: PT as a practical revision method

- (1) At present, PT is do-able in Bartley.

I personally find the IT support (in setting up the labs and printing/saving the logs) important. Now that a reliable lab TSO is trained to do the IT support in your absence, the 1st obstacle is removed. To spread to other teachers, structures need to be set in place to make PT less threatening and less time consuming to get the buy-in first. The school's COP (community of practioners – sch's reflective practice – where chem/phy trs meet for 2 periods a week) would be a good platform to start PT rolling on a bigger scale. Teachers should be paired and work on manageable chunks (e.g on selected topics), read and discuss logs together during COP and as a team prepare the necessary materials after that. Teachers' ERB (electronic record book – where lesson plans are recorded) reflection can be a follow up from COP. With COP and ERB – I feel PT is still do-able on a bigger scale.

I feel that I am able to proceed with 3E1 because I am equipped with the skills, am convinced of the benefits against the greater amount time required, with the necessary resources to do so.

Leo MY is an exceptional case who is able to do it under minimal instructions and guidance and on her own. She has been convinced of the immense benefits from the start and hence the motivation to proceed.

Though the TLLM Ignite Application is not successful (which would give an impetus for PT to expand further), PT will still continue in 2010 with a targeted stream (Sec 3) for both Physics and Chemistry. It will be selective in terms of the coverage of topics involved and the focus will be to use the chat-logs as a focal discussion point for teacher development in the area of teaching and learning. It is hoped that through such collaborative discussions, will teachers be developed in the skill of reading the logs to generate useful practical knowledge to be translated into effective T&L strategies.

- (2) Whether PT is implementable in all public secondary science classrooms really depends on the competence level and preference style of the teachers, the school environment and the support given.
- (3) For a new Secondary 3 class – I would plan the PT schedule into the SOW, but not for all topics. i.e I would alternate PT revision with traditional revision. There would be fewer sessions in Sec 3 as compared to Sec 4, as time is required to build certain concepts, skills as well as the SPA Assessment foundation. PT schedule would also be scheduled to be compatible with the assessment structure. Findings and insights from previous year's chat-logs will also yield new ways of teaching. These should also be included in the SOW.