Science and Mathematics Education Centre

Classroom Use of Multimedia-Supported Predict–Observe–Explain Tasks to Elicit and Promote Discussion about Students' Physics Conceptions

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This thesis is submitted as part of the requirements
for the award of the degree of Doctor of Philosophy
of the
Curtin University of Technology

March 2002

ACKNOWLEDGEMENTS

To Jeanette:	thanks for your wonderful support and enduring patience throughout this study—it's been much appreciated. You're a marvel!
To Alison and Melissa:	the following pages will serve as bedtime reading for you...seriously though, may your own learning be rich, enjoyable and life-long.
To Denis and Maureen:	my first and best teachers! I am forever grateful for the wonderful opportunities you have given me.

Sincere thanks are expressed to my supervisor, David Treagust. Your regular and prompt feedback and guidance has been professional and your support for my endeavours over the period of this study has been much appreciated. Thanks also to my assistant supervisors, Shelley Yeo and Mario Zadnik, who made significant contributions to the genesis of this study. I also gratefully acknowledge the assistance of Peter Taylor and Alan Harrison in the early stages of this study. To my current colleagues in the Education Faculty at UTS, especially Gilda Segal, thank-you for your moral support and encouragement. Finally, thanks to the two teachers who bravely volunteered for this study—it was a privilege working with you.

ABSTRACT

This study investigates two secondary science classes using an interactive multimedia program that was designed for use in small groups to elicit and promote discussion of students' pre-instructional conceptions of motion. The software was designed and constructed by the author and incorporated sixteen digital video clips, primarily focussing on projectile motion, showing difficult, expensive, time-consuming or dangerous demonstrations of mostly real-life, out–of–classroom scenarios. The program used the predict–observe–explain (POE) strategy to structure the students' engagement with each scenario—the clips acting as stimuli for the sixteen POE tasks. This strategy involves students predicting the outcome of a demonstration and discussing the reasons for their prediction, observing the demonstration and finally explaining any discrepancies between their prediction and observation (White & Gunstone, 1992). The choice and sequence of the video clips, as well as the multiple-choice options available to students in the prediction phase of each task, were informed by alternative conception research and the history of science literature.

This interpretive study uses constructivism as a theoretical perspective to explore three main issues relating to the use of the multimedia-supported POE tasks: firstly, the students' learning conversations during their use of the POE tasks; secondly, the use of the program as an instrument to probe students' science conceptions; and thirdly, the affordances and constraints of the computer-mediated environment for the POE strategy. Students worked in pairs and were required to type full sentence responses that were recorded by the computer for later analysis by the researcher. In addition, the students were required to make pencil and paper drawings during some tasks. Other data sources for this mainly qualitative study included audio and video recordings of student discussions, interviews with selected students and their teachers, classroom observations, and student questionnaires.

Findings suggested that students participated in meaningful small group discussions at the computer and the program acted as an efficient and convenient teaching instrument to elicit and record their conceptions of motion. Indeed, the multimedia nature of the program offered fresh and exciting opportunities that mark a new development in the use of the predict-observe-explain strategy in science education. The findings have implications for authentic technology-mediated learning in science classrooms.

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The following publications and conference papers developed from aspects of the research contained in this thesis:

Journal Articles

Kearney, M., & Treagust, D. F. (2001). Constructivism as a referent in the design and development of a computer program which uses interactive digital video to enhance learning in physics. *Australian Journal of Educational Technology, 17*(1), 64–79.

Kearney, M., Treagust, D. F., Yeo, S., & Zadnik, M. (2001). Student and teacher perceptions of the use of multimedia supported predict–observe–explain tasks to probe understanding. *Research in Science Education, 31*(4), 589–615.

Conference Presentations

Kearney, M., & Treagust, D. (1999, July). *Using multimedia supported POE tasks to probe student understanding.* Paper presented at the 30th annual conference of the Australasian Science Education Research Association, Rotorua, NZ.

Kearney, M., & Treagust, D.F. (2000, April). *An investigation of the classroom use of prediction–observation–explanation computer tasks designed to elicit and promote discussion of students' conceptions of force and motion.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, USA.

Kearney, M., & Treagust, D.F. (2000). Constructivism as a referent in the design and development of a computer program which uses interactive digital video to enhance learning in physics. In R. Sims, M. O'Reilly & S. Sawkins (Eds.), *Proceedings of the 17th annual conference of the Australasian Society for Computers in Learning in Tertiary Education* (pp. 57–68). Coffs Harbour, Australia: Southern Cross University.

CHAPTER 1
INTRODUCTION

1.0 Overview of chapter

This qualitative research study focuses on authentic technology-mediated learning in science education. The literature contains numerous media-comparison studies in this field but researchers have only recently begun to focus on what Edelson (1998) termed the "fertile use of technology in adapting science practice for the purpose of learning science" (p. 326). This thesis sought to capture and explore the meaningful use of educational technology in two science classes. Qualitative data sources are used under an interpretive methodology to provide insights into the students' and teachers' use of computer-mediated predict–observe–explain (POE) tasks. The study, which adopts a constructivist learning perspective to explore issues relating to collaborative learning, interactive educational multimedia and the use of the POE strategy, has implications for both the science education and educational technology communities.

This chapter introduces the context, nature and purpose of the study. The background to the thesis is described followed by a discussion of the research questions and methodology, the significance and limitations of the study.

1.1 Background to the study

This study adopts the theoretical perspective of constructivism. The core view of constructivist learning suggests that learners construct (rather than acquire) their own knowledge, which is strongly influenced by what they already know (Driver & Easley, 1978). Consequently, students are considered to learn science through a process of constructing, interpreting and modifying their own representations of reality based on their own experiences. (An overview of the whole belief system based on constructivism is outlined in section 2.2.) Social constructivism acknowledges the social dimension of learning and espouses the notion of students co-constructing and negotiating ideas through meaningful peer and teacher discussions (Solomon, 1987). Learning science from a social constructivist perspective involves students making meaning of the world through both personal and social processes (Driver, Asoko, Leach, Mortimer, & Scott, 1994).

Learners come to science classrooms with a range of strongly held personal science views and the elicitation of these ideas is central to pedagogy informed by constructivism (Driver & Scott, 1996). The process of eliciting students' pre-instructional ideas not only helps teachers to identify common alternative conceptions and inform subsequent teaching episodes but also offers students an opportunity for learning (Duit, Treagust, & Mansfield, 1996). Students are motivated to find the correct science view and meaningful discussion can take place (Taber, 1999). From a social constructivist position, when students engage in this process in a collaborative setting, they receive an opportunity to articulate and clarify their own views and reflect critically on their own and others' views. This process can lead to consensual meaning-making and knowledge integration (Linn & Hsi, 2000). Some instruments which have been used to elicit students' science ideas include student journals, concept maps, student drawings and diagrams, interviews and diagnostic multiple choice tests (Treagust, Duit, & Fraser, 1996). Another tool promoted by White and Gunstone (1992) for efficiently eliciting student ideas and also promoting student discourse about these ideas involves students predicting the result of a demonstration and discussing the reasons for their predictions, observing the demonstration and finally explaining any discrepancies between their predictions and observations. This strategy is known as a predict–observe–explain procedure and was a central feature of the computer program used in this study.

This study takes up the challenge of Carr (1991) to further investigate "ways in which teachers can elicit students' prior ideas as the basis of further learning" (p. 22). It seeks to answer questions relating to the classroom use of a technology-mediated probe of understanding—multimedia-supported POE tasks. The computer environment was used to scaffold the POE strategy and to take advantage of the digital video medium to present real-world demonstrations as stimuli for the tasks. Two science classes used the computer program in a collaborative learning environment to elicit students' pre-instructional science views and promote reflection on and discussion of these views. The collaborative use of computer-mediated POE tasks for these purposes has not been reported in the literature. A related goal of this thesis is to respond to the call from theorists such as Roth, Woszczyna and Smith (1996) for further research on the affordances and constraints of technology-mediated learning in the science classroom. For example, one focus of this study is the computer task's role in facilitating collaborative sense-making. In this way, the thesis makes a contribution to the literature base on constructivism and computer-supported collaborative learning in science education.

1.2 The research questions

The study is essentially a qualitative, dual case study involving two classes using computer-mediated POE tasks that were designed and constructed by the author as a probe of understanding. The study has three lines of investigations. Firstly, it uses a social constructivist perspective to investigate the students' conversations as they engaged with the computer-mediated POE tasks. Secondly, it investigates the use of the tasks as an instrument to elicit students' science ideas. Teacher perceptions are explored followed by a comprehensive description of the students' alternative conceptions elicited through their interaction with the program. Finally, the study focuses on the student and teacher perceptions of the multimedia-supported POE tasks. Hence there are three main questions in this study, each with three subsidiary questions:

Research Question 1 (refer to chapter 6 for full discussion)
To what extent do the computer-mediated POE tasks promote meaningful discussion about students' science ideas?
Subsidiary questions to Research Question 1

I. To what extent do the students articulate, justify and reflect on their own ideas?
II. To what extent do the students reflect on the viability of their partner's ideas?
III. To what extent do the students co-construct ideas and negotiate shared meanings?

Research Question 2 (refer to chapter 7 for full discussion)
Does the students' engagement with the program effectively elicit their personal science views?
Subsidiary questions to Research Question 2

I. Do the teachers perceive the program to be a useful probe of students' science views?

II. To what extent do the students reveal any alternative conceptions?
III. What are the students' alternative conceptions and are they consistent with the science education literature?

Research Question 3 (refer to chapter 8 for full discussion)

What are the perceived affordances and constraints of the computer-mediated environment for the predict–observe–explain strategy?

Subsidiary questions to Research Question 3

I. What are the student and teacher perceptions of the level of student control of the POE tasks?
II. What are the students' and teachers' perceptions relating to the use of the digital video clips to observe the events in the POE tasks?
III. What are the student and teacher perceptions relating to the use of the digital video clips to enhance relevant contexts in the POE tasks?

1.3 Research design

The study adopts an interpretive, dual case study methodology to investigate two science classes using multimedia-supported POE tasks. Students from a Year 11 physics class and a Year 10 advanced science class from two separate secondary schools in Sydney, NSW used the program in collaborative pairs at the start of their formal study of motion. The dual case study was adopted to gain an insightful qualitative interpretation of what was happening during the implementation of an innovative technology. The use of two classes enabled a deeper understanding of various aspects of the students' and teachers' use of the POE tasks (and was not for comparative purposes). Important variables were too intricate and complex to isolate and measure in a traditional positivist study. Hence mainly qualitative data sources were used, including participant observation, semi-structured interviews with selected students and their teachers, collected documents, questionnaires, and audio and video recordings of student discussions and interactions. The students and their teacher initially completed two background questionnaires that provided some quantitative data for the study.

The research questions and interpretive methodology in this study are contrary to the typical media-comparison questions and empirical procedures employed by many earlier studies of technology use in science education (Weller, 1996). Indeed, the nature of the research questions and methods used in this study are firmly aligned with recent literature in this field. For example, Squires and McDougall (1994) argued the futility of researchers trying to describe what software is designed to do. They suggested that a more pertinent question is 'how is it used?' and 'what do learners and teachers do with it?' Collins, Hammond and Wellington (1997) advocated similar research questions, making suggestions such as 'how do teachers and learners use software?' and 'what type of learning outcomes were they trying to achieve by using it?' They also stressed the importance of context in educational technology research: "It is what you do with IT that counts, not IT itself that makes a difference. Context is everything and this leads us to look at the key classroom variables of learner, teacher and software" (p. 27). Roth et al. (1996) advocated that more basic questions need to be addressed through qualitative studies, moving the focus away from the computer as a factor external from cognition and bringing the focus on the learners and the process of learning mediated by the technology. The research questions and methodology used in this study were made in the light of these suggestions and follow the classical ethnographic question about a chosen naturalistic setting, "What is happening here?" (Erickson, 1986, p. 121).

1.4 Significance of the study

The thesis could effectively be summarised as an exploration of issues surrounding three main foci (see Figure 1.1): use of the POE strategy, the design and use of

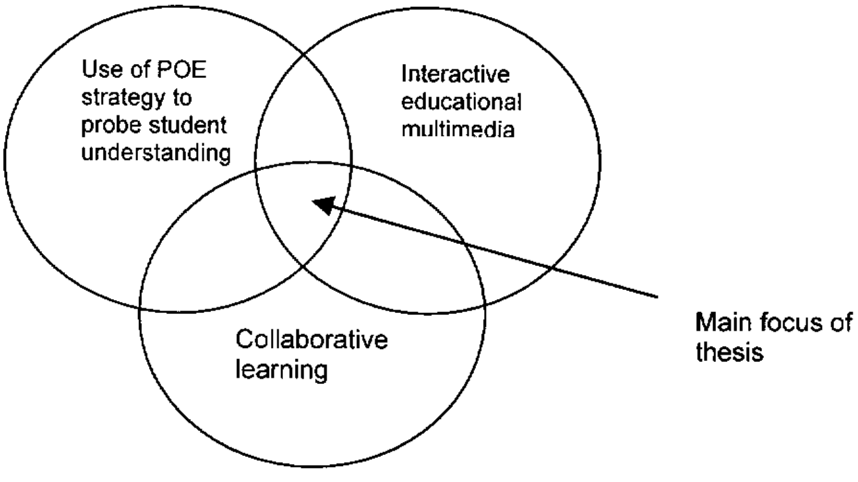


Figure 1.1 Focus of this research study

interactive educational multimedia and collaborative learning in science education. These issues are explored from a constructivist learning perspective and give rise to five inter-related areas of significance for educational research. Firstly, the study makes a contribution to the literature base on the implementation of constructivism in science classrooms. Secondly, it investigates a new development in the use of the POE strategy in science education. Thirdly, it explores the meaningful use of educational multimedia in learning science, and fourthly, it makes a contribution to the emerging field of computer-supported collaborative learning (CSCL). Finally, the study has implications for teaching introductory physics courses, in particular the Stage 6 physics course in NSW Australia (see NSW Board of Studies, 2001).

1.4.1 Application of constructivist strategies in the classroom

The effective and efficient use of constructivist strategies by busy teachers with limited time to teach science needs further attention. Research findings on constructivist learning have had only limited influence and impact on the practice of science education in the classroom and the design of science education curricula (Ben-Zvi & Hofstein, 1996). The following question was posed by Perkins (1991) a decade ago: "How does constructivism inform the moment to moment choreography of the teaching-learning process?" (p. 19). This same question still needs investigation today, especially in relation to technology-mediated learning. For example, theorists such as Jonassen and Reeves (1996) have advocated further research of students learning *with* computers (rather than *from* or *about* computers) under a constructivist learning framework. This study investigates the use of a computer program designed to efficiently elicit students' ideas and initiate student reflection on and discussion of their pre-instructional science views. Thus it is an attempt to contribute to the body of research that discusses the practical incorporation and implementation of constructivist strategies into technology-supported science teaching programs and the science curriculum.

1.4.2 A new development in the use of the predict–observe–explain strategy

The computer program used in this study represents a new development in the use of the POE strategy (refer to section 4.3). The computer environment affords many possibilities for presenting science-based POE tasks in the constructivist classroom. For example, the computer can control the sequencing of the POE procedure, effectively creating a student-centred task. Further, the computer can record and collate student responses for the teacher, and support the digital video medium (refer to section 4.2.5). These aspects have subtle but distinctive pedagogical benefits for the use of the POE strategy and these are explored in chapter 8 (findings related to Research Question 3). Hence the study has implications for the use of the POE strategy in science classrooms.

1.4.3 Meaningful learning using multimedia in science education

This study has wider implications for the use of multimedia in science education. The video medium has been used widely in science instruction for over two decades but has often been used in a didactic fashion where students learn passively. Although schools have spent a large portion of their budgets on multimedia software and appropriate hardware, educational multimedia has generally received widespread criticism for its lack of cognitive engagement with science learners (refer to section 2.3.3). This research with two classes using a multimedia-based program was designed to cognitively and socially engage the learner and promote meaningful learning.

1.4.4 Computer-supported collaborative learning

The study has implications for the broader field of computer-supported collaborative learning (CSCL). This emerging field of educational research is concerned with how technology can support collaboration between learners (see section 2.4.7). A strong focus of recent research in this field has naturally been on peer learning *through* computers (or peer learning *outside* the classroom) and developments that make use of online technologies. Consequently, research focusing on collaboration *at* the computer (Crooks, 1999) has been somewhat neglected (Tao, 2000). The study attempts to contribute to this neglected but still important literature base of computer-supported peer learning *within* classrooms.

1.4.5 Fulfilment of introductory physics syllabus aims

The topic of motion (in particular projectile motion) was chosen as the domain for the computer program used in this study. There were numerous reasons for this choice and they are discussed in section 4.2.4. One reason for choosing this topic is that motion is an essential part of all introductory physics courses. For example, motion is a focus of the core module *Moving About* in the preliminary Stage 6 physics course in NSW, Australia (see NSW Board of Studies, 2001, p. 35). Indeed, projectile motion is a focus of the core module *Space* in the HSC Stage 6 physics course (see NSW Board of Studies, 2001, p. 49). The program used in this study also relates directly to other major aims of the current NSW Stage 6 physics syllabus. For example, students are expected to develop further skills in "communicating information and understanding" and "working in teams" (p. 8). Students are expected to develop knowledge of "... the process and methods of exploring, generating, testing and relating ideas" (p. 12) and to "... predict outcomes and generate plausible explanations related to observations" (p. 14). The use of multimedia is also encouraged in this syllabus: "Interactive media experiences that are related to theoretical concepts" (p. 6) are encouraged. Indeed, the following technology-mediated experiences are recommended: "The use of animation, video and film resources that can be used to capture/obtain information not available in other forms" (p.9). The use of the computer-mediated POE tasks designed for this study is directly related to the fulfilment of these broad aims. Hence this study has a direct relevance to the implementation of the NSW Stage 6 physics syllabus.

1.5 Limitations and assumptions

1.5.1 Financial and time constraints

Cost and time constraints during the development of the computer-based POE tasks resulted in some limitations in this study. The program was completed solely by the author at virtually no cost. (Software and professional advice was fortunately available through the author's workplace at the time of development—refer to chapter 4.) This low budget, coupled with the author's limited multimedia authoring experience, created some rather amateur qualities in the program. Although unrelated to the pedagogical aspects of the program, the screen design and general graphic design of the program needs improvement. Such qualities may have indirectly influenced the students' motivation and perceptions reported in the study.

The limited time available for the program's development meant that only 16 POE tasks were created. Although this turned out to be the optimal number of tasks for the computer lab time available with the students, further research in this area should allow a greater variety of task settings and hence give more allowance for the time-consuming tasks of constructing these multimedia-based tasks (including the filming of appropriate scenarios!)

The time limit on the study (refer to section 5.6) also meant that some key issues could not be fully explored. For example, the study did not directly attempt to formally investigate conceptual change issues relating to the students' use of the program. Similarly, there was no attempt made to explore other important issues such as gender and culture. A longer-term study may indeed aim to explore these important issues.

1.5.2 Choice of Year 10 advanced science class

The Year 10 advanced class at the boys' school was initially going to be a Year 11 physics class. However, due to circumstances beyond the researcher's control, this class was unavailable and it was decided that the Year 10 advanced class would be quite suitable for the study. (Indeed, a pre-requisite for the use of the program was the students' lack of formal study in the domain of motion!) However the actual physics concepts behind most of the POE tasks were more relevant (in terms of syllabus links) for Year 11 students. Although every effort was made to convince the Year10 students that the program was important to their studies, (indeed most of them were going to progress to the senior physics course in the following year), some students may have perceived some lack of relevance for their particular Year 10 course and this may have affected their perceptions and engagement with the program.

1.5.3 Student and teacher beliefs

Students' own views of the nature of science, and their beliefs about the role of the teacher, can affect their perceptions and responses and indeed their whole attitude to programs designed on constructivist principles. For example, if students view science as a mere collection of unrelated facts they will not be as receptive to the types of activities presented in the POE tasks used in this study. If they view the teacher as a person who 'spoon feeds' information, they will again be unreceptive to the notion of the computer tasks eliciting their ideas. The backgrounds of both classes are explored in chapter 5 to confront some of these issues. However, the limited scope of the study restricted these investigations and students' views on these subjects may well have influenced some perceptions presented in the study.

1.5.4 Probing student understanding in collaborative groups

The use of the program by pairs of students (or dyads) is a significant change from the typical individual focus of other studies probing students' understanding. For example, interviews, diagnostic multiple-choice tests and student journals are usually completed individually (Duit et al., 1996). By using the computer-based POE tasks in pairs, ideas elicited and documented by the computer are not necessarily the views of individuals and indeed may be socially mediated ideas (within the small groups). It is important to acknowledge that the findings reported in chapter 7 do not necessarily reflect individual points of view and may well be socially formulated by student dyads. (Indeed, this prospect of peer learning was a major reason for arranging students in pairs!) Alternatively, they may represent the views of a dominant member of the group. Taking the individual as the unit of analysis, this lack of detail on each student's own preconceptions could be seen as a possible limitation to the findings from chapter 7 in particular.

1.5.5 The novelty effect

The *novelty effect* acknowledges that a simple change in environment for students may increase their motivation and affect consequent positive learning effects. If this change is adopted at a later time, it could be less effective as the novelty diminishes! As other researchers have noted, computer-based materials are prone to producing this effect (e.g., Clarke, 1985). The main way of controlling it is to undertake research studies for a longer period of time, with time series observations. However, due to the time constraints of this study, this measure was not possible. Although almost all students in this study were experienced computer users (see section 5.9), for some students the use of a new interactive multimedia program was possibly a novelty, especially in a science-learning context. The possibility that these students' perceptions and actions were affected by this *novelty effect* represents a limitation in the findings for this study.

1.5.6 Assumptions about collaborative learning

The term *peer collaboration* is used throughout this thesis and needs to be clarified. Some theorists use this term in a broad sense. For example, Rogoff (1998) uses the term *collaboration* to include face-to-face mutual involvements such as routine conversation, teaching, tutoring, cooperative learning and even participation in shared endeavors such as between correspondents, readers and authors. However, this study will follow the meaning given by Linn and Burbles (1993) and Damon and Phelps (1989) who suggest that *peer collaboration* is one of three forms of peer learning where students work jointly on the same task and begin at roughly the same level of competence. This is distinct from *cooperative learning* where different roles are taken in team-based activities or *peer tutoring* where one student instructs another in an expert/novice relationship. Damon and Phelps (1989) recommended peer collaboration as the ideal peer learning structure for the social construction of knowledge.

1.5.7 Assumptions about the role of the computer in peer learning

The thesis adopts certain assumptions about the role of the computer in peer learning that are somewhat contrary to some theorists in the CSCL movement. This study does not promote the role of the computer as 'an extra partner' or 'member of the collaborative group' as advocated by Brophy (1995) and Kelly and Crawford (1996). Rather, the thesis adopts the position that the role of the computer is to provide students with a 'resource' or 'tool' as discussed in Pea (1993) and Roth (1996). This role involves the computer presenting and supporting inscriptions or representations that can provide a focus for peer discussions.

1.6 Overview of thesis

Chapters 2 and 3 provide a review of literature relevant to this study. Chapter 2 discusses the related literature on constructivism and educational technology in science education and provides a background from which the study emerged. Chapter 3 gives a review of the related literature on alternative conceptions research in mechanics, the domain chosen for the POE tasks. This chapter facilitates the analysis of students' views elicited in the study (relating to Research Question 2) and provides a preliminary insight into issues relating to the program's design. Chapter 4 describes how constructivism and related literature from both the science education and educational technology fields informed the design and development of the computer program used in this study. This discussion is designed to facilitate a full understanding of some methodology issues in chapter 5 and provide a more transparent insight into the study's findings and conclusions presented in chapters 6 to 9. The students' learning conversations at the computer (relating to Research Question 1) are analysed in chapter 6; their elicited science views (relating to Research Question 2) are discussed in chapter 7; and teacher and student perceptions of their use of the multimedia supported POE tasks (relating to Research Question 3) are outlined in chapter 8. A summary of findings and conclusions is provided in chapter 9.

1.7 Conclusion

This thesis explores the use of a computer-mediated probe of understanding from a constructivist learning perspective. The study involves a new development in the use of the POE strategy in science education and has implications for the computer-supported collaborative learning movement and the authentic use of multimedia in science classrooms. This research focuses on students' learning conversations at the computer, the students' personal science views elicited from their engagement with the program and the perceived affordances and constraints of the computer environment for the POE strategy.

CHAPTER 2

REVIEW OF THE RELATED LITERATURE ON CONSTRUCTIVISM AND EDUCATIONAL TECHNOLOGY IN SCIENCE EDUCATION

2.0 Overview of chapter

This chapter outlines the basic tenets of constructivism, the theoretical perspective taken in this thesis. Relevant literature is examined with three main foci, relating to the three objectives of this study. Firstly, the literature relating to social constructivism is discussed and will be used in chapter 6 as a framework to analyse the learning conversations that occurred between students in this study. Secondly, the literature relating to alternative conceptions is examined as an introduction to a more specific review of associated research in the domain of mechanics in chapter 3. Literature relating to the predict–observe–explain strategy is introduced in this section. An overview of educational technology is given to 'set the scene' for the development (refer to chapter 4) and use of the multimedia program in this study and also to provide a background for the third focus of this chapter—the literature base supporting the constructivist use of computers in science education.

2.1 Introduction

Constructivism is a belief system based on a relativist ontology, assuming that reality is known only in a personal and subjective way by the knower: "Reality exists only in the context of a mental framework (construct) for thinking about it" (Guba, 1990, p. 25). This view is completely contrary to the conventional positivist paradigm, which adopts a realist ontology, assuming that reality has an observer-independent nature, unchanging over time and embodying a universal 'truth'. A common criticism of constructivism is that anyone's construction of the world is as viable as another and therefore the world only exists as constructed in the mind of the knower—a view known as solipsism (Duit, 1995). However, knowledge must not only be viable personally but also in the social contexts in which actions are to occur (Tobin & Tippins, 1993). Knowledge is constructed within these social contexts (acknowledging that the world exists)! Epistemologically, constructivism is based on a subjectivist position (Guba & Lincoln, 1989). The metaphor of *construction* aptly summarises the position that knowledge is built in the minds of learners through their own personal backgrounds, experiences and aptitudes: "Knowledge is constructed and adapted as a result of successive experiences and reflections" (Tobin, 1990, p. 30).

Again, this is in contrast to the conventional positivist paradigm that adopts an objectivist epistemology in associating knowledge with a representation of some aspect of the physical world around us. However, from a constructivist perspective, knowledge is adaptational and comprises concepts that have proved viable in the knower's experience. A viable construction is any mental or physical action that fits in with one's experiences and prior understandings (Hardy & Taylor, 1997), and so knowledge (from a constructivist view) does not tell us about the world but about our experiences in the world. Learning from a constructivist perspective is thus an adaptive process that organises one's experiential world; it is not discovering an independent, pre-existing world outside the mind of the knower (Matthews, 1992).

2.2 Constructivism in science education

2.2.1 Background on constructivism in science education

The nature of scientific knowledge. Any account of teaching and learning science needs to consider the nature of the knowledge to be taught (Driver et al., 1994). From a constructivist perspective, "the objects of science are not the phenomena of nature but constructs that are advanced by the scientific community to interpret nature" (p. 5). Science does not give us truth but offers a way for us to interpret events of nature and to cope with the world. Indeed, scientific knowledge was invented in order to make sense of observations, which are themselves open to individual interpretations (Matthews, 1992). As a result, scientific knowledge consists of formal specified entities and the relationships between them: "...the symbolic world of science is now populated with entities such as atoms, electrons, ions, fields and fluxes, genes and chromosomes..." (Driver et al., 1994, p. 6). However, this body of knowledge is not separate from knowers but represents socially constructed and validated knowledge based on experiences in the world: "...science is viewed as a set of socially negotiated understandings of the events and phenomena that compromise the experienced universe" (Tobin & Tippins, 1993, p. 4).

The aims of science and science education. From a constructivist perspective, the aim of science is to make sense of a universe of phenomena in terms of knowledge that is viable (or making sense of our sense impressions). Hence, learning science can be considered as learning new ways of making sense of the world and constructing viable models to fit current understandings and experiences (Tobin, 1990). This is in contrast to a positivist perspective, where the aim of science is to discover the true nature of reality and how it truly works; and learning science is about knowing these truths about the world.

Traditional learning in science. Behaviourism was the dominant learning theory in science education for most of the 20th century, and is deeply embedded in an objectivist epistemology, with a focus on students replicating certain behaviours. The teacher provides a set of stimuli and reinforcements that are likely to ensure that students give appropriate responses. This traditional way of teaching is characterised by teachers adopting a transmission view of learning: what the teacher says is what the learner hears and therefore knows (Gunstone, 1990) and is reflected in the old adage: 'tell them what you are going to tell them, then tell them, then tell them what you told them'. Such approaches in science education have resulted in frequent rote learning and recall of concepts and appropriately applying formulae, with limited understanding (McRobbie & Tobin, 1997).

Constructivist learning theory in science education. The constructivist movement marked a significant move away from the dominance by behavioural psychology, with a new emphasis on the role of concepts and conceptual frameworks in human learning (Novak, 1988). Constructivist pioneers in science education such as Driver and Easley (1978) and Novak (1977) initiated a movement which also branched away from earlier cognitive science efforts such as Piaget's stage theory to focus on the actual substance and context of students' explanations: "Achievement in science depends ...upon specific abilities and prior experience than general levels of cognitive functioning" (Driver & Easley, 1978, p. 62). The core view of constructivist learning suggests that learners actively construct (rather than acquire) their own knowledge, strongly influenced by what they already know. Indeed, Ausubel (1968) had pre-empted this notion when he wrote his now famous words:

> If I had to had to reduce all of educational psychology to just one principle I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly. (p. vi)

Knowledge is not 'transplanted' to a person's mind as if the mind were a blank slate waiting to be written on (Cobern, 1993). Alternatively, learners make sense of the world by interpreting new information in terms of what is already known:

> Fundamentally, constructivism asserts that we learn through a continual process of constructing, interpreting, and modifying our own representations of reality based on our experiences with reality. (Jonassen, 1994, p. 35)

Hence, teachers need to be attentive to students' pre-instructional ideas and elicit these views prior to formal instruction: "Prior knowledge is used to make sense of experience and as a consequence, teachers should give close attention to the prior knowledge of each student in the class" (Tobin, 1990, p. 31). Indeed, students may hold alternative conceptions (ideas contrary to the accepted science view—refer to section 2.2.3) owing to their varied prior experiences and existing knowledge. Thus the role of the teacher is to recognise these strongly held conceptions that children bring to the classroom and provide experiences that will help them build on their current knowledge of the world (Duit & Confrey, 1996). In this sense, constructivist teachers act as a 'tour guide' mediating between children's everyday world and the world of science (Driver et al., 1994).

Student views of teaching. The epistemological commitments of students can be an important influence in their learning of science (Novak, 1988). Learners come to the classroom with their own views of knowledge, their own conceptions about teaching and learning and perceptions of purpose and progress. For example, students often have transmissive views of teaching and learning, and passive views of their own role in the learning process. These views must be addressed before constructivist strategies can be effective, as learners are responsible for recognising and evaluating their own beliefs and deciding whether to reconstruct them: "If the learner's ideas and beliefs about the processes of learning and teaching are in conflict with them recognising, evaluating, reconstructing their existing science ideas and beliefs then little progress is possible" (Gunstone, 1990, p. 17).

2.2.2 Social constructivism in science education

One of the problems with early cognitive science theories was the lack of consideration given to the social dimension of learning. Piaget largely ignored socio-cultural processes whilst early developments in constructivism focussed on individual cognitive growth. Solomon (1987) looked to sociology for new ideas that would help with these problems, stressing the importance of meaning-making with others and social interactions in the classroom. She emphasised the co-construction of ideas through student discussion: "As students interact with one another...they develop ideas that, because they are held in common, create a universe of discourse, a common frame of reference in which communication can take place" (p. 68). Vygotsky (1987) also emphasised socially constructed concepts and referred to the fluid boundary between scientific and everyday ways of knowing. He conceptualised speech or language not as a mere expression of fully developed thought but as a means towards the development of thought: "thought is restructured as it is transformed into speech. It is not expressed but completed in word" (p. 251).

Social constructivism builds on the works of Vygotsky and Solomon and acknowledges that learning is a social activity in which learners are involved in constructing consensual meaning through discussions and negotiations with peers and teachers. Learning science under a social constructivist framework involves students making meaning of the world through both individual and social processes (Driver, Asoko et al., 1994). Knowledge is personally constructed but socially mediated: "...the individual and social components [of constructivism] being parts of a dialectical relationship where knowing is seen dualistically as both individual and social, never one alone, but always both" (Tobin & Tippins, 1993, p. 21). Students are given opportunities to test the viability of new knowledge claims with peers and link these new ideas with personal experience and existing knowledge (McRobbie & Tobin, 1997). Hence, from a social constructivist perspective, the development of understanding by writing and discussion of ideas with peers is an essential part of learning and involves articulation, clarification, elaboration, negotiation and consensus-making: "Accordingly, students should be encouraged to be involved in putting language to ideas, testing their understandings with peers and listening and making sense of the ideas of other students" (p. 197). Students can identify and articulate their own views, exchange ideas and reflect on other students' views, reflect critically on their own views and when necessary, reorganise their own views and negotiate shared meanings (Prawat, 1993).

Background on peer learning. The effectiveness of peer learning was generally accepted across educational circles during the 1980s and represents a move away from the traditional role of the teacher as the fountain of knowledge. Damon and Phelps (1989) advocated three major approaches to peer learning. Firstly, peer tutoring occurs where one child instructs another in a novice/expert relationship that is similar to the traditional teacher/student relationship where one party transmits expertise to another. Secondly, cooperative learning is an 'umbrella term' that covers a diversity of team-based learning approaches such as the use of teams, achievement groups or learning centres. It uses no more than five or six students, usually organised in a heterogeneous fashion, where roles are usually assigned. Thirdly, peer collaboration is where students work jointly on the same task (unlike cooperative learning where different roles are taken) and begin at roughly the same level of competence. Linn and Burbles (1993) used a similar taxonomy of peer learning, labelling their three groups as tutored learning, cooperative learning and collaborative learning. Like Damon and Phelps (1989), they emphasised that any small group activity may involve a combination of these types.

The benefits of cooperative learning are well studied and documented. Decades of research on cooperative versus competitive learning structures have confirmed that cooperative learning has positive effects on students' achievement, problem solving and motivation to learn (Nastasi & Clements, 1991; Qin, Johnson, & Johnson, 1995; Slavin, 1990). For example, Johnson and Johnson (1987) conducted a meta-analysis of 378 studies comparing the achievements of people working in cooperative groups, working individually and working competitively. More than 50% favoured cooperation while less than 10% favoured individual efforts. Cooperative groups fostered individual academic achievement and enhanced motivation for all types of students regardless of ethnicity and age. Cooperative learning encourages better attitudes towards peers and improved self-esteem (Slavin, 1990) but sometimes places too much emphasis on managerial roles rather than cognitive roles (Rogoff, 1990).

Peer collaboration uses groups that are not highly structured, specialized roles are not assigned and tasks tend to be open-ended (Blumenfeld, Marx, Soloway, & Krajcik, 1996). Peer collaboration provides a supportive environment that encourages students to experiment with and test new ideas, thereby critically re-examining their own conceptions (Damon & Phelps, 1989). It is rich in mutual discovery, feedback and sharing of ideas and is especially useful for tasks that require new insights and the development of deep knowledge structures (rather than tasks which rely on formulae and procedures).

> ...peer collaboration's promise lies in provoking deep conceptual insights and fundamental developmental shifts in perspective. This is because peer collaboration encourages experimentation with new and untested ideas, thereby demanding a critical re-examination of one's own assumptions. (Damon & Phelps, 1989, p. 13)

Creating successful groupwork is not simply a matter of putting students together in groups. "Students do not automatically become more involved, thoughtful, tolerant or responsible when working with others" (Blumenfeld et al., 1996, p. 37). Important issues to be considered in any type of group learning include group membership, the roles of teachers and students, the nature of activities and the evaluation of groups' activities. Encouraging effective groupwork depends on developing open ended, investigative tasks (encouraging articulation, discussion and debate); creating group goals that encourage individual accountability and providing strategies and support to promote interactions between students (Slavin, 1990). How the group is organised is another important consideration.

The outcomes of peer learning arrangements include cognitive development (one focus of this study), how to get along with peers, enhancement of intergroup relations, teamwork skills and respect and responsibility in social relations (Jonassen, Peck, & Wilson, 1999; Rogoff, 1990). From a social constructivist perspective, the two main outcomes are to encourage construction of shared knowledge (see next subsection); and to enable students to join educated communities of discourse (Wegerif & Mercer, 1996). Peer learning helps students to construct knowledge by building communal knowledge through conversation and also becomes an introduction to the scientific language, values and ways of knowing associated with the discipline of science (Blumenfeld et al., 1996).

> The learners use of everyday language, their learning to use the technical register of science in discussing and engaging in argument over the meanings they are giving to experiences, and the evidence relating to their knowledge claims are important components in making these connections [between experience and extant knowledge] and testing the viability of their knowledge. (McRobbie & Tobin, 1997, p. 197)

Constructing shared knowledge in peer groups. Tobin (1990) summarised the value of constructing shared knowledge through peer discussions. This process allows learners to articulate and clarify their own ideas, exposes learners to their peers' views (through attentive listening), and allows learners to evaluate and reflect on their own and others' ideas and see if they are viable. It gives learners an opportunity to justify and defend and possibly debate their own views and allows them to negotiate and make meaning together. The promotion of dialogue and reflection through peer learning is most important: "Social constructivists believe that meaning making is a process of negotiation among the participants through dialogues or conversations" (Jonassen et al., 1999, p. 5).

Articulation is a first step to clarifying one's own ideas. "Until children's ideas are publicly articulated, neither teacher nor child can consider their meaning and validity" (Gallas, 1995, p. 29). Articulation of students' ideas in order to communicate with a peer sharpens their conceptions and often leads to recognition of new connections: "When students make their thinking visible, they can identify the many ideas they have about a scientific topic" (Linn & Hsi, 2000, p. 90). Hence, it is no surprise that much of the conceptual change research in science education prompts learners to articulate their science understandings as a first step in shifting their preconceptions towards standard scientific explanations (Taber & Watts, 1997).

The process of reflection involves actively monitoring, evaluating, and modifying one's thinking and comparing it to both expert models and peers. "We have within our capability the constant renewal of our own world view. Human reflection is the key to understanding and creating anew a world in which we coexist with others" (Duffy & Cunningham, 1996, p. 182). This type of thinking requires a combination of both individual and collaborative reflection (Lin, Hmelo, Kinzer, & Secules, 1999). On an individual level, Solomon (1987) emphasised that children's language can 'turn inward' to become the basis of inner speech and so of thought itself. On a social level, processes such as explaining, clarifying, elaborating, justifying, evaluating, analysing, synthesizing, questioning, and restructuring occur as students reflect on what they have learned and as they interact with peers (Tobin, 1990). Peer discussions make ideas visible to others in the class and give learners important opportunities to share multiple viewpoints, listen carefully to others' ideas and promote mutual respect between peers (Linn & Hsi, 2000).

If a person is involved in a group discussion, it is necessary to *listen* to the views of others and determine whether or not he or she agrees. This makes interpretation of others' ideas a social affair, and feedback from the listener becomes a crucial stage in the process of clarifying and reflecting on one's own and others' ideas:

> Without confirmation from a listener we can hardly believe in our own stories about the experiences we have had, let alone in those of others. So in our talk and our discussion we give each other access to these experiences, and then argue over our opinions about their interpretation. (Solomon, 1998, p. 58)

Indeed, the process of listening becomes easier as the students use language appropriate for their own age and background (Hand, Treagust, & Vance, 1997). Learners use their own stories, metaphors and analogies when discussing abstract and complex ideas. Hence, students' ideas raised in peer discussions are more likely to be elaborated and open than in a whole class discussion (Kelly & Crawford, 1996).

Student negotiation of meaning goes beyond the traditional role of students helping each other to get the correct answer to a problem but is concerned with creating opportunities for students to explain and justify to other students their developing ideas; listen to and understand and reflect on the viability of others' ideas and subsequently reflect on the viability of their own ideas (Taylor, Fraser, & White, 1994). Justifying and selecting viable theories during peer discussions is a key part of learning under a social constructivist framework: "Justifying one's position over another and selecting those theories that are viable can lead to consensus that is understood by those within a peer group" (Tobin, 1990, p. 32). Although sometimes consensus will not occur (individuals will always cling to their own constructions and personal theories), most students appreciate the chance to compare their ideas with peers before negotiating new meanings: "...belief in our own ideas is astonishingly hard to form or to maintain without the collaboration of others...It is almost as though we do not understand what we think unless we can discuss it and receive back the effects it produces when our friends respond" (Solomon, 1987, p. 63). So through these peer exchanges, students become aware of others' ideas, seek reconfirmation of their own ideas, and reinforce or reject their own personal ideas (Maor & Taylor, 1995).

Wegerif and Mercer (1996) used the term *exploratory talk* to describe this type of dialogue where partners engage critically but constructively with each other's ideas. "Statements and suggestions are offered for joint consideration...challenges are justified and alternative hypotheses are offered...knowledge is made more publicly accountable and reasoning is more visible in the talk" (p. 51). They suggested that exploratory talk is the type of language practice that is essential for successful participation in educated communities of discourse. Linn and Hsi (2000) used the term *knowledge integration* to describe this process of comparing ideas, distinguishing cases, identifying links among notions, seeking evidence, and sorting out valid relationships. During this process, students seek diverse perspectives and robust ideas that can be applied widely; they link ideas, distinguish and reorganise conceptual frameworks and reconsider scientific ideas.

As students construct shared knowledge in peer groups, teachers take on the role of supporting students' interactions with their peers and the physical world. They assist students to reconstruct their existing conceptions and determine the viability of their new ideas: "teachers become mediators of students' encounters with their social and physical worlds and facilitators of students' interpretations and reconceptualisations" (Taylor et al., 1994, p. 3). Indeed, the teacher's role, which is more demanding than traditional classrooms, involves promoting recognition, evaluation and reconstruction of ideas and negotiating the construction of scientifically acceptable knowledge (Hand et al., 1997).

Teachers need to promote mutual respect amongst students by explaining to them the basic tenet of constructivism; the notion that different students can hold multiple perspectives (or 'truths') about a concept at the same time: "Someone else's world view, her belief structure, can be as legitimate as our own" (Duffy & Cunningham, 1996, p. 182). Effective conversations will only take place through a discourse that values argument, reliance on evidence, and explanation (Linn & Burbules, 1993). Students need to learn how to generate ideas in peer discussions, and accept and elaborate on others' ideas without criticising them. Taylor et al. (1994) referred to the need for an *open discourse* in social constructivist learning environments, where respect amongst participants is encouraged to enhance self-disclosure of values and beliefs.

'Talking science' in peer groups. Hawkins and Pea (1987) and Lemke (1990) have argued for the need to reorganise science learning environments so that students come to be able to 'talk science' and to "produce and interpret speech acts involved in participating in scientific activities, rather than just 'hear' science" (Pea, 1993, p. 273). This view looks at science as a discourse, a socially and culturally produced way of thinking and knowing, rather than viewing science in the traditional sense of acquiring

specific facts and procedures. Hence, peer discussions become an opportunity for learners to talk science and learn the discourse of science (Roth, 1995). Indeed, learning science in this context means to achieve a certain level of competence in talking science (Roth et al., 1996). This alternative focus on discussion as a means of encouraging students to learn the discourse and social practices of the science community is linked to a socio-cultural perspective of learning science and considers both the social context and social processes as an integral part of learning (Brown, Collins, & Duguid, 1989; Lave & Wagner, 1991; Rogoff, 1990).

2.2.3 Alternative conceptions

Learners come to classrooms with a range of strongly held ideas which are considered contrary to accepted science views. These ideas may stem from the use of everyday language to interpret science concepts; egocentric, anthropocentric or animistic viewpoints; or the tendency to dismiss non-observable as non existent or the endowment of objects with a certain amount of physical quantity (Driver, Squires, Rushworth, & Wood, 1994). These alternative understandings of science have been referred to as misconceptions, alternative conceptions, preconceptions, naive theories, alternative frameworks, and children's science amongst other terms. (This study will use the term *alternative conception* to refer to students' ideas which are perceived by him or her as a coherent and meaningful alternative to an accepted science concept.) Research on alternative conceptions began to flourish during the 1970s, probably stemming from Piaget's interest in children's ideas (White, 1999). Hundreds of papers have been published revealing common alternative conceptions in a variety of domains (Pfundt & Duit, 1994), with a strong focus in the domain of physics, especially mechanics (refer to chapter 3), dynamics, light, heat, and current electricity.

Probing students' ideas to identify alternative conceptions. The elicitation of student ideas is central to any teaching approach informed by constructivism (Driver & Scott, 1996). It is widely accepted that students' alternative conceptions can form a barrier to learning and hence effective teaching in science requires these strongly held ideas to be made explicit and reviewed. Most teaching strategies designed to help students construct a consensual world-view of science depend upon this initial identification of existing knowledge before attempting to merge this knowledge with currently accepted scientific ideas (Lavoie, 1997). Indeed, this process of eliciting ideas can help teachers to review their own views and help them become more receptive to trying different teaching strategies if they find their present methods are inadequate in changing students' alternative conceptions (Duit et al., 1996)

Social constructivist perspective on eliciting students' ideas. The process of eliciting ideas also can offer the student an opportunity for learning (Duit et al., 1996). Students are often motivated to find the 'correct' science view and this can initiate meaningful discussion: "Classroom discussion of the items in such an instrument [probing understanding] can be used to make important teaching points" (Taber, 1999, p. 97). From a social constructivist perspective, if students' ideas are elicited in a social setting, they receive an opportunity to articulate and clarify their own preconceptions, reflect critically on their own and others' ideas and possibly co-construct reformulated ideas. "Conversations about the ideas brought to lessons by learners and negotiation with that knowledge is a procedure that should not be bypassed without careful thought as to the theoretical consequences" (Carr, 1991, p. 22). The eliciting of students' ideas at the start of a unit of work provides an ideal time to initiate these discussions: "...procedures which elicit students' prior ideas and make these the basis of conversations are needed to bring about helpful change" (p. 22). Indeed, Linn and Hsi (2000) emphasised this elicitation process in a social setting as a starting point in their knowledge integration process: "Knowledge integration includes the process of eliciting ideas, introducing new ideas and encouraging new connections..." (p. 93).

Strategies for investigating students' alternative conceptions. The development of more sophisticated techniques of identifying students' beliefs has accompanied educational research on the importance of both student and teacher awareness of alternative conceptions. For example, the 'interview about instances' technique (Osborne & Freyberg, 1985) and concept maps (Novak & Gowin, 1984) have been widely used with individual students. More sophisticated written tests such as those developed by Tamir (1990) and Treagust (1987) have been useful with larger groups. Predict–observe–explain tasks, student journals, drawings and diagrams, word association and question production are other methods which have been used (Treagust et al., 1996).

Student interviews are acknowledged as the most effective way to probe student understanding: "...the interview is perhaps the most powerful and direct method of assessing students' understanding" (Abdullah & Scaife, 1997, p. 79). The interview can provide extra detail compared to other methods as the interviewer is free to pursue the subject's ideas and clarify ambiguous answers. However, interviews are time-intensive, difficult to apply to large numbers of students and are vulnerable to interviewer bias, even for trained interviewers. Many teachers are not trained to conduct interviews, record and transcribe data and interpret findings (Peterson & Treagust, 1989).

Diagnostic multiple-choice tests have been used widely as an alternative to interviews. These tests are cheap, in a format familiar to students, easy to administer, score and interpret and can be used with much larger groups of students. Peterson and Treagust (1989) outlined a procedure used to develop written diagnostic instruments to identify alternative conceptions. They firstly continued the tradition of using educational research on alternative conceptions to develop distractors for multiple-choice items (e.g., Halloun & Hestenes, 1985a). They also used two-tiered tests where students were firstly asked to choose their response before choosing a reason for this initial response, although students also had the opportunity to write their own prediction or reasons if they didn't like any of the given responses. They emphasised that these types of tests can assist in the process of helping science teachers use the findings of research in the classroom. However, these tests are usually based on previous educational research and hence will only diagnose more common alternative conceptions (Taber, 1999; Tan & Treagust, 1999).

Computer-mediated probes. Treagust et al. (1996) report that computers have been used to investigate students' alternative science conceptions. Most of these studies have used computer simulations; for example, Simmons and Kinnear (1990) used computers to probe conceptual understanding and problem solving strategies as students used a genetics simulation called *Kangasauras.* Goldberg and Bendall (1996) described a strategy built around demonstration tasks administered by a computer videodisc system which used the capability to overlay text and graphics on top of video pictures. The program was designed to elicit prior knowledge in the domain of optics and identify conceptual difficulties in post-instruction students. The program contained a series of appropriately sequenced tasks and used a combination of video and graphics to help students connect the actual phenomena (light rays) with the representation (ray diagram). Students discussed with partners to make explicit their initial thinking about phenomena before making their predictions in the form of a light ray diagram. The program then produced graphic simulations of an expert's ray diagram (the feedback), drawn while superimposed on video stills of scenes.

Expert Systems research has attempted to provide rule-based computer systems which can diagnose students' misconceptions in science (Abdullah & Wild, 1995). For example, Nachmias, Stavy, and Avrams (1990) used a program where students predicted and recorded the shape of a temperature versus time graph for water boiling. The computer recorded the students' graphical predictions and diagnosed inconsistencies using its rule base. They also attempted to progress from this diagnosis function to appropriate remediation and individualised instruction: "In addition to the current usage of the computer in science education for practice, simulation, games and student-directed data acquisition, this technology also may offer the opportunity to identify student conceptions . . . leading towards individualised instruction" (p. 130). As well as being quick and informative, the authors believed these types of expert systems have potential to combine well with intelligent tutoring systems and 'microcomputer-based laboratories' (or MBL's—refer to section 2.4.5).

2.2.4 The predict–observe–explain (POE) strategy in science education

The POE procedure is based on the classic model of research where a hypothesis is stated and reasons are given for why this may be true, relevant data are gathered and results are discussed (White, 1988). A POE task involves students predicting the result of a demonstration and discussing the reasons for their predictions; observing the demonstration and finally explaining any discrepancies between their predictions and observations. The procedure was developed at the University of Pittsburgh (Champagne, Klopfer, & Anderson, 1980) where it was initially labelled a DOE (Demonstration, Observation and Explanation). The procedure generally uses observable, real-time events as stimuli to provoke student thinking about concepts. (Tasks which use this procedure will be referred to henceforth as *POE tasks*).

Background on the use of demonstrations in science education. Demonstrations are an extremely valuable teaching strategy. They can be used to introduce or review a topic, set a problem and connect concepts with real life examples. They can be stimulating and motivating for students and allow teachers to focus student thinking and observation on specific outcomes of events. Demonstrations can save time, make use of equipment in short supply and provide quality control over hazardous experiments (Dawson, 1994). Demonstrations help confer belief of a concept that a student otherwise finds counter-intuitive. The visual aspect of demonstrations provides a complementary way of understanding a concept and may be particularly useful in explaining concepts that have key spatial or temporal relationships (e.g., the concept of centre of mass). Multiple visual examples presented in demonstrations promote the use of correct analogies in forming and transferring concepts. Demonstrations are useful for concepts "which can be seen" (e.g., displacement, velocity etc.) but not as effective for abstract concepts which are not directly observable, such as angular momentum (Gattis & Park, 1997).

Typical classroom demonstrations have traditionally been teacher-centred and conducted with an information transmission view of teaching. For example, Roth, McRobbie, Lucas, and Boutonne (1997) criticised the lack of opportunity for students to engage in the discourse relating to a demonstration before concluding that demonstrations were ineffective learning activities for many physics students. Students were unable to test the appropriateness and suitability of their current ideas for describing, constructing and explaining the phenomena under observation: "The students did not develop the competence to talk about phenomena of interest in a way compatible with scientific canon" (p. 527). They found that students were unable to separate 'signals from noise' and did not know which aspects of the display they needed to focus on to understand the teacher's accompanying theory talk. (This criticism is in agreement with earlier authors such as Driver (1983) who discussed the need to help students focus on what is relevant in a given situation.) Prior alternative conceptions interfered with the development of appropriate student discourses suitable for a particular demonstration. They found that other demonstrations also could interfere with relevant conceptual development and students were generally unable to connect key ideas, especially if deep learning was not a priority in the class. The authors recommended teachers adopt a social practice perspective of knowing and learning that promoted peer interactions and discussions during demonstrations.

Demonstrations and the POE procedure. Many criticisms of demonstrations can be addressed by embedding them in a predict–observe–explain procedure. Associated positive learning effects revolve around the links between the POE procedure and the demonstration of phenomena. The commitment to a prediction enhances students' understanding of the situation involving the demonstration while the reasoning stage provides a further focus for the observation and builds motivation. The observation phase can initiate discussion and foster valuable learning (see next subsection), especially if it is contentious, while the explanation phase also provides a significant opportunity for discussion.

These positive learning effects are enhanced when students are required to write their responses to each component of a POE task. Gunstone (1995) recommends that students write their predictions, reasons and observations to increase their level of commitment, encourage the formation of links between new and old concepts, and help identify non-uniform observations. (Although Palmer (1995) reported a contrary finding that very young children's responses were more detailed using oral rather than written communication. However, this oral feedback was problematic as children could merely repeat what other groups say and could be dominated by loud individuals. He suggested a possible solution for lower primary aged children could be the use of group work in which each group rotated in turn through different POE stations.) As the explanation phase reconciles any differences between the prediction and observation, it is best done via discussion: "reconciliation is better approached via discussion [rather than writing]" (Gunstone, 1995, p. 13).

Background on the nature of scientific observation. Although it may appear straightforward, scientific observation is actually a complex process (Haslam & Gunstone, 1998; Roth et al., 1997). Scientific observations may range from the live viewing of real events (e.g., observing the different shapes of birds' beaks), to the viewing of phenomena through complex, second-hand observations (e.g., observing the centre of the sun using advanced instrumentation). Contrary to popular understanding, scientific observation is not necessarily linked to human sense perception. For example, astronomers observe the sun through machines which can 'sense' neutrinos (Nissani & Hoefler-Nissani, 1992).

It is widely accepted that all observation is interpretation (Hodson, 1986). For students of science, this interpretation arises through one's prior experiences of the world; what one observes depends on what one already knows. Hence, scientific observation is not a simple matter of direct reproduction of stimuli: "*Looking at* is not a passive recording of an image like a photograph being reproduced by a camera" (Driver, 1983, p. 11. Italics inserted.). The quality and usefulness of observations also depends on the language available to the observer. All observation statements need to be expressed in the language of some theory, so "knowing what to observe, knowing how to observe it, observing it and describing the observations are all theory dependent and therefore fallible and biased" (Hodson, 1986, p. 23). Indeed, the language used in students' observations provide an assessment of how well students can use relevant canonical discourse relating to the phenomena studied (Roth et al., 1997).

One aim of science education is to teach students to be observant and be objective and precise in their reporting and recording of events (Driver, 1983). Student observation is held central to the learning of science and hence science curriculum documents and science teaching practices overwhelmingly assert this important skill (eg., NSW Board of Studies, 2001). Observation is naturally considered a crucial component of laboratory work (Gunstone & Champagne, 1990) but just as in other laboratory skills such as recording and analysing data, there is a need to be explicit in developing an understanding of the skill and purpose of observation (Nissani & Hoefler-Nissani, 1992). Distinguishing between observations and inferences, for example, is a difficult task but a crucial one if science classrooms are to use the process of observation for learning (Gunstone & Champagne, 1990). Many observations made by science students reveal a lack of understanding of the nature of observation; and inferences (conclusions reached on the premise of collected evidence) are often made instead.

Haslam and Gunstone (1998) found that a teacher's views of the process of observation have a strong influence on students' views and engagement in related activities. They found students perceived the process of observation as important in their learning but there was a wide-spread misunderstanding of the word *inference*. They generally saw observation as a teacher-directed process with contextual dependencies on four areas: the related area of science (e.g., physics, chemistry, biology etc.); the level of intrinsic motivation of the task; the time required (longer experiments did not gain full attention); and the familiarity of related concepts (if the students knew what would happen, less attention was given to observations). Interestingly, many students believed that physics experiments did not involve observing; they only involved measuring.

Scientific observation and the POE strategy. The process of observation is a crucial stage of the POE strategy, providing feedback to students after committing themselves to a prediction. From a constructivist perspective, the articulation and writing of observations also provide an important insight into students' strongly held ideas and beliefs: "The record they make of their observations either by writing or drawing indicates their understanding of the phenomena" (Driver, 1983, p. 32). This effect of personal beliefs on observations as students engage in POE tasks was discussed by White and Gunstone (1992) who found many variations in students' observations according to what outcomes they had predicted. They found many students tried to hold on to their seemingly inconsistent predictions by explaining their observation in these terms, even when the observation was seemingly unambiguous. A few students interpreted an observation in terms of their predicted results by denying the observation. For example, they would use excuses such as friction to explain why their observation was wrong. Similar results are discussed in Nissani and Hoefler-Nissani (1992) as well as Liew and Treagust (1995): "Their prior knowledge, reasons and expectations influenced their observations" (p. 70). Hence, in the context of probing students' preconceptions, their observations alone can provide a 'window' into their own personal science ideas. Gunstone and Champagne (1990) discussed the crucial role of the teacher in resolving any conflicts in students' observations and considering any implications of the observations made by students. They also warned teachers that students' observations of events will affect their predictions in future POE tasks of related phenomena.

Use of POE tasks as an instrument to elicit students' science ideas. The POE strategy encourages students to decide what existing personal ideas and beliefs are relevant to a situation before evaluating the appropriateness of these views (Gunstone, 1995). As well as providing an effective technique for introducing a new concept, the POE strategy can therefore be a most effective tool for assessing students' understanding of concepts.

> This [POE] procedure...is a sharp, powerful means of uncovering deeply held beliefs about scientific principles and phenomena, in contrast to school tests, which often tap only the veneer of facts and algorithms that students have learned in order to get a good grade. (White, 1988, p. 62)

In the prediction and reasoning phase, students can justify their prediction with reasons based on their interpretation of relevant science concepts involved in each task (Searle, 1995). These reasons (regardless of a correct prediction) are extremely important in the assessment procedure: "In order to investigate alternative frameworks, students' thinking has to be probed in some detail; it is the reasons pupils give for their answers, not the answers themselves, that are important" (Driver, 1983, p. 26). It is important that this prediction and reasoning stage of the POE strategy avoids application of the students' 'textbook knowledge' and elicits their own personal views of the world. Students are more likely to use 'school knowledge' if the event is seen as merely another classroom event. This articulation of personal ideas gives students confidence and helps them to realise they already have ideas that are relevant to a topic (White & Gunstone, 1992). As discussed in the previous subsection, the process of observation itself can reveal pertinent alternative conceptions.

Unlike other probes such as interviews, POE tasks take less time to complete, they can be used with large groups and they do not require special teacher training to administer and interpret results. POE tasks can be used validly and reliably with great frequency, unlike other techniques like concept maps where students soon learn to place more branches for more marks (White & Gunstone, 1992).

Use of the POE strategy in alternative conceptions research. Champagne et al. (1980) used the POE procedure to probe understanding of basic physics concepts held by first year physics students and found that many of these successful physics students retained their pre-instructional ideas. Gunstone, Champagne, and Klopfer (1981) used POE tasks to establish the force and motion beliefs of grade 7 and 8 students while Gunstone and White (1981) used the POE technique to probe understanding of gravity concepts held by first year physics students. The latter study noted a serious inability of students to explain a prediction and resolve discrepancies between observations and predictions. Millar and Kragh (1994) used activities similar to POE tasks in their study of 11 year olds' understanding of motion. They suggested that POE tasks should be endorsed as a style of scientific investigation in curricula, even though the procedure strays from the traditional quantitative investigation by exploring relationships between dependent and independent variables. They concluded that POE tasks form "wonderful observation tasks dependant on the collection of reliable and replicable evidence about the behaviour of the natural world" (p. 34). Liew and Treagust (1995) used whole class POE tasks with secondary school students studying heat and expansion of liquids, solubility and electricity. Their tasks used laboratory-based equipment but talking between students was discouraged. They too found significant effects of students' prior knowledge on their predictions, observation and interpretation of phenomena and concluded that POE tasks can be used by teachers to insightfully design learning activities that start with the students' viewpoints rather than the teacher's or scientist's views.

Use of the POE strategy in conceptual change studies. The POE strategy has been used in many science education studies focussing on conceptual change. Whether used individually or in collaboration with other students, POE tasks can help students explore and justify their own individual ideas, especially in the prediction and reasoning stage. If the observation phase of the POE task provides some conflict with the students' earlier prediction, reconstructions and revision of initial ideas is possible (Searle & Gunstone, 1990; Tao & Gunstone, 1999b).

Searle (1993) studied conceptual change using first year physics students studying forces. This study used an instructional strategy comprising three stages. Firstly, a POE task was used to help introduce the concept and act as a 'vehicle for discussion'. Secondly, another (non-POE) qualitative task was used to promote conceptual change (where alternative concepts existed) to a scientific view. General class discussion and further individual problems also were considered here. Thirdly, a quantitative task provided students with an opportunity to solve real world problems. This was used as an indicator of the success of any conceptual change. The role of the POE task (in stage one) was to expose students to a range of interpretations of physical phenomena apart from their own: "Through this heightened awareness of alterative explanations, it was envisaged that each student would think more deeply about his own views and either modify, discard or hold on to that view" (p. 267). He found that POE tasks were useful in promoting instances of conceptual conflict and provided an excellent vehicle for testing the relative strength of intuitive ideas about force and motion. The POE strategy encouraged students to express their own views about a given situation and allowed a subsequent discussion of those views. This sometimes lead to a consensus scientific view of the phenomena. He emphasised that students' awareness of their own concepts was an important precursor to conceptual change: "Through articulation of their ideas, a deeper understanding of concepts can occur, thus making the transition to a scientific view more likely" (p. 268).

POE tasks were used in a study by Thorley and Woods (1997) to facilitate conceptual change in their study involving Grade 4 students studying electricity. However, they called these tasks *PEOE tasks* to emphasise the phase where students give (or explain) reasons for their predictions. Students worked in small groups and were encouraged to articulate their theories about electrical phenomena and test them against the views of other students and laboratory observations. They found that the POE strategy was effective in moving students beyond the naive views about electrical phenomena. Dissatisfaction arising from disagreements between predictions and observations and also between personal supporters of different explanatory models, motivated students to construct better personal models. The students' ability to consider their own and their peers' theories was crucial to this process. Liew and Treagust (1998) reported that POE tasks can effectively track students' conceptual development by facilitating teachers in documenting student achievement and profiling student progress. They found some students reconstructed and changed their prior conceptions as a result of inconsistencies or contradictions between observations and predictions.

Finally, Tao and Gunstone (1999a,b) used computer-mediated POE tasks designed to provide students with experiences of co-construction of shared understanding or peer conflicts while using a physics microworld. In their study, Year 10 students worked collaboratively in pairs using the force and motion microworld; considering the contexts of a model car (linear motion with or without friction), a spaceship (linear motion without friction) and a skydiver (vertical fall under gravity, with or without air resistance). The program used animation (rather than digital video clips) and students used worksheets to record their work. In each task, students made a prediction about the consequences of certain changes being made to the simulation. Case studies of collaboration were reported for various student dyads and inferences were made as to whether or not these experiences lead to conceptual change. Social construction of knowledge took place through this peer collaboration and in many cases this led to students' conceptual change in the context of the tasks attended to. However, when probed at a later time, many students had regressed to alternative conceptions. Conceptual change occurred for people who were cognitively engaged in the tasks and prepared to reflect on and reconstruct their conceptions.

2.2.5 Summary

Constructivist learning theory acknowledges that students build their knowledge based on their own personal backgrounds and experiences. Students hold on strongly to their personal views of the world and some of these views emerge as contrary to accepted science views and are labelled alternative conceptions. The literature relating to alternative conception in mechanics will be discussed in chapter 3. Predict–observe–explain tasks provide an effective instrument for eliciting students' ideas and have been reported extensively in the literature. The POE strategy structures the learners' engagement with a demonstration, provoking reflection on ideas and relating these views to real situations. However, computer-mediated POE tasks have been reported sparingly.

From a social constructivist perspective, students working in groups can construct consensual meaning through discussions and negotiations. This process may involve students articulating their own views, listening to and reflecting on others' ideas, and reflecting on the viability of their own ideas. Students also receive an opportunity to practise the discourse of science in their peer groups.

2.3 Overview of the field of educational technology

2.3.1 Historical perspective on educational technology

Contrary to many predictions, no modern educational technology has been a panacea for education. For example, television was heralded as a revolution in education but its passive use has dampened these initial claims. Radio, film, computers and the internet have held similar claims but these modern technologies have had marginal impact on the teaching and learning process. "The only significant technological innovations of the 20th century to find a secure place in schools are the loudspeaker, the overhead projector and the copy machine" (Fiske, 1998, p. 11)! This reluctance to accept the latest educational technologies has been a trend throughout history. When written language was an emerging technology, Plato and other ancient Greek scholars claimed that it would weaken the memories of learners and lead to an erosion of the "truth" (Pea, 1985). Of course, an oral culture was soon changed to a scribal culture. Similarly, after Gutenberg invented the printing press in 1452, changing a scribal culture to a print culture, it took schools many years to use textbooks as they were considered a threat to the authority of teachers (Fiske, 1998). So technologies can potentially become a major influence on the way we think and act: "Each new technology—the alphabet, the printing press, the electronic technologies—profoundly changes the way humans come to know and interact with the world" (Norton & Wiburg, 1998, p. 2). With these examples in mind, it is probably a matter of time before the electronic technologies of the 20th Century become mainstream in our education system and are used in a meaningful way.

Computers emerged in education at a time when behaviourism was the dominant learning theory. Hence, the role of computers was to deliver lessons to teach learners, "just as trucks deliver groceries to supermarkets" (Jonassen et al., 1999, p. 6). Skinner's 'fill in the blanks' teaching machines during the 1950s were a classic example, leading to the development of computer-assisted instruction (CAI) during the 1960s and 1970s. These drill and practice and tutorial programs were commonly associated with rote learning and mastery learning. Other early uses of the computer included children learning programming languages such as Basic and Fortran as a foundation for Computer Studies subjects. These subjects emerged from the computer literacy movement, initiated by teachers who wanted students to learn *about* (as well as *from*) computers (Jonassen & Reeves, 1996). However, the focus of these subjects was the technology itself and learning across the curriculum with computers was limited. Early concerns with drill and practice software led to more emphasis on learner-controlled, content-free software such as databases, spreadsheets and word-processing software. This productivity software is still a popular use of computers in education today (Collins et al., 1997).

Cognitive learning theories became popular with educational technology designers as an alternative to behaviourism. These theories emphasise the development of knowledge schemata and learning is viewed as the changing of these schemata, rather than the shaping of behaviour. Information processing became a popular branch of these cognitive learning theories and focused on the memory and storage processes that make learning possible. This approach views the learner as receiving and encoding information much the same way as a computer processes information and has been particularly influential in the development of artificial intelligence (AI) applications, drill and practice software, and the systems approach to instructional design (Roblyer & Edwards, 2000). However, both behaviourism and information processing theories share a transmissive view of instruction (Greening, 1998), where information is considered to be 'stored' in the technology (Jonassen et al., 1999). Indeed, Gagne and Glaser (1987) recommended an approach to instruction which built upon behaviourist traditions and information processing theories. He emphasised the hierarchical nature of learning and his conditions of learning could be used to plan lessons using drill and practice, tutorial and simulation software. (Although, Roblyer and Edwards (2000) point out that only sophisticated intelligent tutoring software could satisfy all of these conditions.)

The child-friendly programming language Logo was developed by Seymour Papert during the early 1980s and had a profound impact on instructional computing. Logo challenged traditional instructional methods, commonly used in drill and practice and tutorial programs, with an emphasis on child-centred exploration rather than teacher-directed instruction. Papert believed that learning best occurs in an active environment in which children participate in the process by constructing objects. He labelled this perspective *constructionism* (as an extension of constructivism) and Logo became synonymous with a way of thinking about computers and learning: "Better learning will not come from finding better ways for the teacher to instruct but from giving the learner better opportunities to construct" (Papert, 1990, p. 3).

Interactive multimedia (refer to section 2.3.3) and communications software developed significantly during the 1990s. Although there were rapid advances in the hardware associated with these technologies (e.g., sound and video capabilities, the internet infrastructure etc.), the role of computers was still often conceived to be one of a surrogate teacher or source of knowledge, rather than a tool for learning (Jonassen et al., 1999). Despite the development of other popular learning theories over the past two decades, most educational computing software today continues to adopt similar behaviourist models of learning (Reeves & Harmon, 1994; Wiburg, 1995).

2.3.2 Directions in educational technology research

Early research on computer-assisted instruction (CAI). Early studies in the field focussed on the popular CAI applications, with a strong focus on drill and practice and tutorial programs. These were generally quantitative, media comparison studies that focussed on potential achievement gains and instructional efficiency. For example, Kulik, Bangert, and Williams (1983) conducted a meta-analysis of 51 studies in secondary schools and found that computer-based teaching raised students' final examination scores, improved attitudes towards computers and towards the course they were taking, and reduced time for learning. These positive effects particularly applied to low aptitude students. Roblyer (1990) reported on a large review of educational technology studies conducted from 1980 to 1987 and found that computer applications (again mainly drill and practice software) had a statistically significant positive effect in a majority of areas examined. They found no particular evidence of any link between student ability level and effectiveness of computer-based applications and like the Kulik et al. (1983) study, student attitudes towards school and the subject area were affected by computer use and learning time was generally reduced. Word-processing also was found to have a positive effects on writing and Logo was found to enhance problem solving and creativity.

Weller (1996) examined the impact on science learning of classroom and laboratory use of computers in K–16 from published research between 1988 and 1995 by reviewing a wide variety of studies involving CAI over a range of topics—although two-thirds of the studies were again media comparison studies. He concluded that most endeavours to use computers in science education falls short of providing inviting, interesting opportunities for students to explore and explain phenomena of the natural and physical world. There were limited opportunities for students to investigate their own questions and other problems answered by scientists through the ages.

There has been widespread criticism of this early educational technology research. For example, Clarke (1994) contends that the increases in achievement reported in the meta-analysis studies such as Kulik et al. (1983) are more likely to be due to the teaching pedagogy used in the programs rather than the computer or any associated media attributes. He contended that these studies usually compared computer-based and traditional methods but suffered from confounding variables. Many of these studies didn't control factors such as instructional methods, curriculum content or novelty. Berger, Lu, Belzer, and Voss (1994) also criticised these quantitative studies in science education: "Meta-analyses provide an overall average measure of how computers affect learning in science but cannot provide some of the specific information, indicating how certain programs have affected the learning process and the specific contexts" (p. 471).

Selwyn (1997) believed there were three main problems with most educational technology research. Firstly, most studies adopted an overtly optimistic overtone or a techno-romantic view of the computer: "Unlike other areas of educational innovation and change, the introduction of computers in schools has been largely uncontested with any criticism swept under a utopian wave of opinion that computers are inherently and unequivocally a 'good thing' for education" (p. 305). Secondly, many studies in the field have avoided qualitative methodologies and thirdly, there seems to be a wilful blindness to the social and cultural contexts and implications of technology.

Emergence of qualitative studies in educational technology research. Kozma (1991, 1994) responded to Clarke's criticism of educational technology research by suggesting that researchers look at technology not as a medium to deliver information but in the context of the learner actively collaborating with the medium to construct new knowledge. Media theory is a combination of understanding ways in which students can use the unique processing capabilities of computers as well as how to employ these capabilities to enhance learning. Indeed, some pedagogical enhancements would be impossible without the capabilities of new technologies and there is a need to understand these links (Kozma, 1994). He suggested that research questions should move away from the traditional questions seeking to find which medium is better, as these comparative studies don't examine processes or contextualize findings. Instead, there is a need to find the appropriate uses of various media capabilities and the ways in which these capabilities may be used to influence the learning for particular students, tasks and situations. "An understanding of the way that media capabilities, instructional methods and cognitive processes interact in complex social situations will allow us to take advantage of these capabilities" (p. 17). Indeed, Salomon, Perkins, and Globerson (1991) emphasised the futility of an educational research agenda focussing on technology itself: "...we are aware that computer technology in and of itself is of little interest. What is of interest and can potentially affect students' intellect are the kinds of programs and tools that can be used with this technology, as well as the kinds of activities that they afford" (p. 2).

The use of qualitative studies that incorporate class observations, interviews, artifact analysis etc. can provide appropriate data about relevant social and cognitive processes in order to explore these issues. Such detail is often missing from quantitative data (Kozma, 1994). There is little doubt that learners enjoy using computers and are motivated and engaged by multimedia material. These programs can provide opportunities for learners to take more control of their learning and research should focus on associated issues: "…we are not so much interested in the number of clicks students make when they explore material but the quality of their thinking and talking" (Collins et al., 1997, p. 122).

Example: Computer-supported collaborative learning (CSCL) studies. Examples of these 'new' types of educational technology studies can be drawn from the computer-supported collaborative learning (CSCL) movement (e.g., see Koschmann, 1994)—a rapidly emerging field of study that is concerned with how technology can support peer collaboration between learners. (Indeed, sections of this particular study make a contribution to this field.) There are numerous perspectives from which to study this phenomenon. For example, Crooks (1999) identified four referring to student interactions *at*, *around*, *through* and *in relation to* computers. Interactions *at* computers typically involve two learners gathered at a computer to solve a problem. It is the most familiar form of collaboration (and is the form of collaboration used in this study). Interactions *around* a computer refer to groups of students who are sharing a number of computers in a common space. Interactions *through* a computer refers to the collaborations which occur through computer networks where students are usually separated in time and space (e.g., email). Finally, interactions *in relation to* computers occur when collaborators are able to reference some experience which was previously shared at the computer; mediation is not dependant on current use of the computer (e.g., class notes placed on the web may initiate collaboration away from the computer). CSCL also can be considered *within* the classroom (the focus of this study), *across* the classroom (with computers connected to a network) or *outside* the classroom (via the internet). Alternatively, CSCL also can be categorised using a temporal reference, for example, synchronous collaboration through chat rooms and conferencing facilities or asynchronous collaboration such as email. Many recent CSCL studies have explored new and exciting developments that make use of these on-line technologies. For example, web-based facilities can support and keep track of synchronous dialogue amongst students that then serve as a public archive of conversations: "…conversations can be stored, reflected on and reacted to, creating a common knowledge base that is open to review, comment and manipulation" (Blumenfeld et al., 1996, p. 39). From a social constructivist perspective, the success of these web-based communications depends on the opportunities afforded to students for critiquing the ideas of others as well as soliciting alternative ideas, sorting out conflicting information and responding to other learners (Linn, 1998). Nevertheless, this strong focus on on-line settings has resulted in computer mediated collaboration *within* classrooms being neglected as a research setting: "…CSCL studies in the naturalistic setting of the classroom, which is still the dominant place for formal science learning, appear to have been neglected" (Tao, 2000, p. 4).

2.3.3 Interactive educational multimedia

The term *multimedia*, which has been used for several decades, until recently meant the use of several media devices such as slides with an audiotape. The term also has been associated with CDROM technology and World Wide Web use, irrespective of the material they contain. However, educational multimedia can be defined as the integration of media such as text, pictures (including drawings and photos), sound (including speech), animation and video for the purposes of teaching and learning. These media typically incorporate only visual and auditory modalities, although recent virtual reality technologies have endeavoured to incorporate other senses. Interactive video disks linked to a computer were a popular combination for supporting multimedia programs during the 1980s before the computer developed the capabilities to coordinate these various 'symbol modes' as computer-mediated, interactive multimedia (Kozma, 1991). The term *interactive* in this context refers to the process of empowering the learner to control the environment. Like most technology innovations, the first success of interactive multimedia was in the commercial sector. For example, touch-screen videodisc technologies combined graphics, audio and video in shopping malls, museums and retail outlets (Jonassen et al., 1999). Interactive multimedia is now arousing much interest in education as its techniques become more manageable and affordable and its potential benefits for communication and meaningful learning are demonstrated (indeed, one of the foci of this study).

Benefits of interactive multimedia. Phillips (1997) advocates the use of multimedia for content that is hard to visualise and for helping students to link concepts (e.g., dynamic processes where it is important to understand the relationships of moving objects). Other appropriate uses include simulations and demonstrations of expensive, dangerous or complex processes where understanding may be hindered by the mechanical detail of actually performing the process; or where there is no possibility of using the real equipment. Collins et al. (1997) discussed three benefits of interactive multimedia for learning. Firstly, extended access gives learners the opportunity to access information beyond the normal range of class resources. Secondly, enjoyment and engagement (e.g., from audio-visual stimulus) is evident in many learners. Thirdly, control, autonomy and responsibility are given to learners, allowing students to explore and discover by themselves.

Criticism of interactive multimedia. During the 1990s multimedia was hailed as the panacea to all education problems, particularly for the 'MTV generation' of students, who were accustomed to continuously changing, multimodal shows (Jonassen et al., 1999). "Educators . . . claimed, as Edison did about motion-picture film, that students should and would eventually learn everything they needed to know from multimedia" (p. 87). However, multimedia has so far not made a substantial impact on schools. It has mainly been used to deliver instruction and usually lacks clear goals or adequate instructional strategies. Using multimedia merely because it provides multisensory representations of ideas has not been enough to support meaningful learning. For example, Dillon and Gabbard's (1998) meta-review of quantitative research relating to hypermedia in education found that the benefits are limited and "not in keeping with the generally euphoric reaction to this technology in the professional arena" (p. 322).

Madian (1995) asked the important question about multimedia: 'what are students learning?' He suggested that multimedia may well discourage students from thinking deeply and using language effectively. Madian expressed concern that children's imagination and use of words for expression is not promoted well by multimedia: "Too little of their imagery comes from their own imaginations" (p. 17). He suggested that music or graphics are seldom needed to enhance a well written passage and most multimedia provides an example of 'glitz offered as substance': "The medium has made the trivial more attractive, but the medium has not encouraged in-depth research and thinking" (p. 16). Wiburg (1995) shared Madian's hesitancy to adopt the 'multimedia wagon' and suggested that teachers need to become more critical users of multimedia. Reeves and Harmon (1994) also warned of this blind acceptance of multimedia: "Developers of IMM programs...assume that since IMM *ought* to be effective for instruction, they *are* effective for instruction" (p. 501). Yelland (1999) warned educators to be careful with "electronic crack" (p. 56) for kids that encourages more drill and practice disguised in the cloak of glitzy multimedia effects. She warned against teachers using the "pizazz of sega games to squirt a bit more information into the heads of children in the name of productivity" (p. 56). She believed that multimedia and educational technologies in general had simply amplified the activity of teachers and the passivity of children.

Most educational multimedia has traditionally adopted a behaviourist approach to design (Stemler, 1997). It is natural for the content expert to structure information in a linear form that is logical to them and to impose this structure of knowledge on the student, giving them little or no control: "There is a natural tendency to take this transmissionist approach and try to implement it on the computer" (Phillips, 1997, p. 26). As a result, sequential e-book type programs with little interaction have been most popular. In these types of programs, students tend to click on the next screen before reading its contents (Phillips, 1997). Similar findings were expressed by Yeo, Loss, Zadnik, Harrison, and Treagust (1998) who studied students' interactions as they used a commercial piece of interactive educational multimedia in the domain of physics. They found that without intervention, students did not cognitively engage at a deep level.

Interactive digital video. The term *interactive video* can be defined as any video which the user has more than minimal 'on-off' control over what appears on the screen. The 'media attributes' (Salomon et al., 1991) of interactive digital video include: random access, allowing users to select or play a segment or individual frame (picture) with minimal search time; still frame or pausing, allowing any frame of the video clip to be clearly displayed (or 'frozen') for as long as the user wishes to view it; step-frame or toggling, enabling users to display the next or previous frame, and slow play enabling the user to play the video at any speed up to real time in a forward or backward direction. Although most of these features were possible in the older VHS video tapes, computer-mediated digital video made these capabilities far more efficient and accurate. "This ease of access to any part of the video changes its function from a linear element used to introduce or enhance instruction to an integral resource that can be explored and analysed in detail." (The Cognition and Technology Group at Vanderbilt (CTGV), 1991, p. 38). Although not included in the program used in this study, recent developments with this medium include the use of 360-degree cylindrical panoramic images. For example, Apple© Computer's QuickTime© VR clips can handle simple panning, tilting, and zooming about given viewpoints (Chen, 1995).

However, Laurillard (1993) questioned the term 'interactive video'. She described *interactivity* as something that involves intrinsic feedback on what a student does; the information in the system should change as a result of this action. Video is not interactive in this sense. For example, nothing in a video changes when a student rewinds it, just as nothing in a book changes when you turn a page. Alternatively, she described video as having a high level of controllability, especially compared to television, and hence prefers the term *active video* rather than interactive video. Video is self-paced and gives opportunities for students to reflect on what they are doing: "The only advantage of video over TV is in the self-pacing provided by greater learner control, which at least allows students to reflect on the interaction they have witnessed..." (Laurillard, 1993, p. 118).

During the 1980s there was great expectations about the educational potential of interactive video. (As mentioned previously, interactive video was a term commonly used to describe a computer linked to a videodisc player during this time. Although it was a first step on the way to full multimedia on a computer, it was mainly used in whole class settings or large groups as individual settings were limited by costs and equipment access.) It was heralded as a major new dimension in the use of a computer for teaching and learning and again, like many previous educational technologies, it was considered an agent for educational change. Three of its significant claims reflected long standing claims of CAI generally: firstly, students learn at their own pace, allowing repetition and revision; secondly, when used as a medium for demonstrations, it released the teacher to spend more time with small groups and thirdly, it was motivational and students enjoyed the richness of visual images: "The visual element of the package gave pupils, who are experienced TV watchers, familiar ground to work within" (Norris, Davies, & Beattie, 1990, p. 90). Many studies involving interactive video were analysed, again with mixed results. For example, Atkins and Blissett (1989) analysed the types of learning activities in which 9–13 year old students engaged themselves during the use of an interactive video program. More than half the time was spent in passive roles of reading, watching and listening. Only 23% of the time was spent in discussion, although it was shallow and action-centred (i.e., discussing what to do with the program) and reflection and strategic thinking was often missing. A major study by Norris et al. (1990) evaluated the effectiveness of interactive video in British schools and made the familiar conclusion that the future of the technology rested strongly on appropriate teacher professional development. They were unable to conclude whether interactive video actually enriches learning and whether the cost of the technology was justified.

Learner control. The notion of learner control was first introduced in relation to CAI and refers to students taking control over some aspects of their computer-mediated learning environment. It may imply control over the pace of information presented, the order or sequence of information presented, the timing of information presented or the quantity of information presented (Becker & Dwyer, 1994). It also may refer to control over difficulty levels, content, contexts, and the method of presentation (Stemler, 1997). Traditional research on learner control has focussed on how much or what type of control is best and findings have been mixed (Williams, 1996). Learner control of the content and sequencing in a program can encourage self-management of learning, although some students may not be exposed to all of the instruction (Kinzie, Foss, & Powers, 1993). Some form of structural guidance was found to be a key when students were given control over the sequence and pacing of a computer program incorporating interactive video (Arnone & Grabowski, 1991). This latter study found that learner control students who also received some guidance, performed better than other students (including students who had complete learner control but no guidance) and also developed higher levels of curiosity. Individual differences were a factor in some studies where learner-control performances were disappointing and students were simply not capable of making good use of the control they were given. Students' prior knowledge and ability were found to predict student success under learner control. For example, students with little prior knowledge were not able to monitor their comprehension and not able to estimate the degree of instructional support needed. Importantly, students with low ability lacked the learning strategies to deal with any extra learner-control (Dillon & Gabbard, 1998; Stemler, 1997; Williams, 1996).

Constructivist perspectives of educational technology (refer to section 2.4) are associated with a high degree of learner control of software: "The more learner controlled the instructional systems are, the more generative they are; that is they require learners to generate or construct their own knowledge" (Williams, 1996, p. 977). However, Williams suggests that constructivists should be considering issues beyond which type of control is better or other traditional issues such as comparing learner control to program control. Instead they should be considering questions such as 'how can learner-control be made more effective?' For example, Harper and Hedberg (1997) emphasised the use of cognitive support tools to help learners who become daunted by the high degree of creative freedom and choice of direction in constructivist multimedia programs (refer to section 2.4.4).

Motivation issues associated with learner control. Becker and Dwyer (1994) looked at the impact of increased learner control on levels of intrinsic motivation. Previous studies had established strong links between enjoyment and intrinsic motivation and learner control over the goals, pacing and difficulty level of activities (Lepper, 1985). The Becker and Dwyer (1994) study investigated a multimedia setting and found that multimedia may increase self-determination and intrinsic motivation depending on the *perceived* learner control of the task. Students were motivated by feeling in control of their own learning, and being aware of this control. Despite criticisms by Clarke (1983), who dismissed any motivational effects associated with computers as a *novelty effect*, findings linking learner control with motivation continue to be a powerful reason for using computer-based technology in the classroom (Roblyer & Edwards, 2000).

2.3.4 Summary

One trend in schools through the 20th century has been their reluctance to accept educational technology innovations and developments. Consequently, only rather simple 'modern' educational technologies such as overhead projectors are widely accepted and used by teachers in schools (Fiske, 1998)! Computers and associated technologies are no exception to this trend, despite the massive expenditure on these items by schools. So far computers have not provided a panacea for education, similar to radio, television and film before them! A transmissive view of instruction has dominated the use and development of educational software since the introduction of computers into schools during the 1980s. This view has been strongly influenced by behaviourism and also information-processing theories. Early research in the field comprised mostly of quantitative, media-comparison studies, although qualitative methodologies have now emerged as a viable and often desirable alternative. Studies from the CSCL movement focus on technology-mediated peer learning and provide excellent examples of these new types of educational technology research.

Exciting developments have occurred with interactive educational multimedia during the 1990s. For example, interactive digital video developed from an expensive, rather clunky medium involving external laserdisc players, to a cheaper, user-friendly medium with many capabilities that facilitate learner control. However, most multimedia programs still commonly adopt a behaviourist approach to design with glitzy multimedia effects simply providing a disguise for drill and practice style, didactic instruction.

2.4 Constructivist use of computers in science education

2.4.1 Problems with 'traditional use' of educational technology

Directed instruction based on behaviourism and information-processing theories (refer to section 2.3.1) have proven to be deficient in some areas (Roblyer & Edwards, 2000). For example, activities are often not motivating or relevant and students receive limited opportunities to do problem-solving or work cooperatively. There is often little scope to deal with learner differences, especially students' existing ideas and views, and life-long skills such as metacognition are ignored (Phillips, 1997). Adopting a transmissive approach to learning, computers have traditionally been used to present information, ask questions and judge answers, all of which humans do better; at the same time, students have been required to receive, store and retrieve information, all of which computers do better (Jonassen et al., 1999). Learners have been viewed as passive recipients of instruction, with an emphasis on memorising facts and isolated skills. These traditional didactic approaches have focussed on learning *from* technology; using computers to transmit information to the learner in the hope that they will be more efficient than teachers e.g., TV, films, CAI. "In much of the computer education community we are still building and selling Skinner's teaching machines" (Wiburg, 1995, p. 390).

2.4.2 Background on constructivist use of educational technology

Jonassen and Reeves (1996) advocated that students learn *with* computers (rather than *from* computers) under a constructivist learning framework (refer to section 2.2). Computers can serve as a catalyst for facilitating constructivist environments if used in ways to promote reflection, discussion and problem-solving. "Technology is best used as a cognitive tool to learn *with* rather than a surrogate teacher. Pedagogy and content matter most; technology and media are only vehicles, albeit powerful ones" (Reeves, 1998, p. 53. Italics inserted). Indeed, Spitulnik, Stratford, Krajcik, and Soloway (1998) emphasised the construction rather than transmission of knowledge in science education, supporting student-designed and student-built intellectual products; the collaborative design of 'technology artifacts' such as dynamic models (e.g., using spreadsheets) and multimedia documents (refer to section 2.4.4). "Computer-based interactive learning environments allow student-directed activities rather than computer-driven tutoring" (p. 365). In a similar fashion to Papert's constructionism, they claimed that the construction of these products can facilitate students' explanations of science phenomena, testing of ideas and development of conceptual understanding. Such uses also supported Edelson's (1998) recommendation that technology be used productively to adapt science practice for the purpose of learning science. He believed that technology could help students experience the work of scientists by helping them collect and share data, analyse data through the use of modelling and visualisation software, gather and evaluate evidence and communicate with peers.

2.4.3 Teacher roles and beliefs

It is not necessarily the program that makes the software effective but more how the students and the teachers use it. Maor and Taylor (1995) reported on two classes that were monitored using the *Birds of Antarctica* database. In the class where the teacher used a constructivist approach to learning, students showed more development of inquiry skills. Such higher level thinking skills were much less evident in the class in which a more didactic approach occurred. Although the two classes used the same software, the outcomes were different, according to the teacher's epistemology: "The computer in itself does not necessarily promote inquiry learning; it is the teacher and the students whose collaborative grasp of the tool constitutes inquiry" (p. 852). Hence, constructivist learning can take place with multimedia (and indeed other software types) if the teacher adopts a constructivist epistemology. Collaborative discussions, debates, negotiations and reflections need to be encouraged by the teacher to develop higher order thinking skills associated with constructivist learning. Multimedia and other programs may help this process but ultimately it is the teacher's beliefs and actions which determine the ultimate success of these lessons: "...teachers' epistemologies continue to perform a central role in mediating the quality of student learning" (p. 852).

2.4.4 Constructivist use of interactive multimedia in science education

In his 1992 Millikan lecture, Robert Fuller emphasised the “ah-ha” experience as common for students who are intrinsically motivated in their learning of physics. In his discussion of intrinsic motivation and multimedia use in science education, he discussed aspects of intrinsic motivation such as fantasy, challenge and curiosity (Malone, 1981) and related these to multimedia use. For example, he suggested that the rich visual images and sounds in multimedia can help to create and communicate real-world ‘physics stories’ as an alternative to the traditional physicists’ fantasy world of boring and mundane point particles, fields and frictionless planes! Such uses of multimedia are motivating for students and help them to relate physics to the real world (Fuller, 1992). These sentiments provide a fitting summary of the dominant themes in the literature surrounding the constructivist use of multimedia in the science classroom. Such programs use rich world contexts for students to consider, are relevant to the learners’ goals and experiences, are interactive and provide a choice of pathways. They also help students to link information and encourage consensual meaning-making. Examples include video-based laboratories, information landscapes and student-authored multimedia.

Video-based laboratories. Interactive video presentations can be used to make observations, measurements and gather data about events. Computer digital video systems allow students and teachers to capture video of experiments they perform themselves by storing the video on their computer’s hard drive. When connected to spreadsheets, students can then use the interactive video clips to efficiently gather data and make graphs and other representations to analyse and model their data. Many studies have shown these video-based laboratories to be motivating and authentic learning experiences for students (Beichner, 1996; Gross, 1998; Laws & Cooney, 1996; Rodrigues, Pearce, & Livett, 2001; Rubin, Bresnahan, & Ducas, 2001). Indeed, Squires (1999) described these video-based laboratories as facilitating a constructivist learning environment by promoting open-ended exploration in an authentic learning environment; this is particularly so when the learner chooses and captures his or her own film clips. Rubin et al. (1996) introduced this notion of learner-shot video in mathematical analysis when students used *CamMotion* to explore a dance sequence and analyse the motion of their own bodies.

An important learning outcome in most physics courses is for students to learn to observe their own world more carefully. The use of digital video gives teachers and students sophisticated tools to observe dynamic processes and physical phenomena in intricate detail. Our human ‘window’ into the natural and physical world is limited and much phenomena of interest to the science community exists as scales beyond our temporal, perceptual or experiential limits (Kozma, 2000). However, video can help to expose students to such phenomena and overcome these traditional barriers by showing dangerous, difficult, expensive or time consuming demonstrations not normally possible in the laboratory (Hardwood & McMahon, 1997). For example, video can create the illusion of slowing down or speeding up time either through filming techniques or by using the capabilities of the medium such as using slow motion or toggling whilst viewing the clips (refer to section 2.3.3). These facilities are particularly useful when considering time-dependant phenomena prevalent in many science episodes, particularly in the mechanics domain. Digital video clips also allow students to observe accurate and reliable replications of demonstrations (Bosco, 1984) and enable students to enjoy a continuous, seamless experience, unlike the experience of live demonstrations that may be given days apart (Hoffer, Radke, & Lord, 1992). Hence, interactive digital video makes possible the detailed observation of interesting laboratory or real life events and is considered an important technology in the area of computer-based learning in science (Weller, 1996). Such real-life scenarios can make science more relevant to the students' lives (Duit & Confrey, 1996; Fuller, 1992; Jonassen & Reeves, 1996), and help students build links between their prior experiences and abstract models and principles (Escalada & Zollman, 1997).

Information Landscapes. Modern designs of interactive multimedia can be created to facilitate learning in rich environments that 'situate' the content to be learned. These programs adopt the view that learning and thinking are fundamentally situated, being a product of the content, activity and culture in which they are developed and applied (Brown et al., 1989). The term *information landscapes* was introduced by Florin (1990) (cited in Harper, 1997, p. 38) to describe these settings (or 'intellectual amusement parks') in which students can situate their learning. In these programs, students create their own meaning and understandings of phenomena as an alternative to one generated by their teacher or the package designer. "In these environments, knowledge is not a thing (a product) delivered to students; rather, knowing is a situated activity (a process) supported by the use of technology tools" (Barab, Hay, & Duffy, 1998, p. 15).

An early and popular example of software designed on these constructivist and situated cognition principles is *The Jasper Woodbury Problem Solving Series* (CTGV, 1990). This series of programs for 5th and 6th graders provides opportunities for students to learn advanced mathematics problem-solving skills in the context of high interest video-based adventures (presented on interactive videodisc). Students create answers to problems and also generate problem statements in this environment. Two Australian ecology-based programs—*Exploring the Nardoo* and *Investigating Lake Ileuka*—have been widely acclaimed as excellent examples of software designed with constructivist perspectives. In both programs, interactive multimedia is used to create realistic information landscapes where students can 'roam through' and create their own meanings and understandings of the phenomena they encounter (Harper & Hedberg, 1997). Like the Jasper series, the video medium is used to create real-life scenarios within the package, providing students with problems from practice and opportunities to conduct realistic investigations using multimedia tools provided in the program to support them: "Bounded learning environments can be designed to encourage student-centred investigations and knowledge constructions" (p. 13). Students are encouraged to be active, constructive and cooperative as they conduct these authentic investigations.

Student multimedia authoring. Jonassen et al. (1999) advocated the use of multimedia as an authoring platform for students to represent their own meaning; possibly as part of inter-disciplinary, large scale projects. In making their own multimedia, students improve their self confidence by planning, producing and sharing productions in a cooperative learning environment. Zucchermaglio (1993) (cited in Winn and Snyder, 1996, p. 131) used the metaphor of *empty technologies* to describe this type of authoring software that is flexible, child-centred and acts like 'shells' waiting to be filled by anything the student or teacher wishes. Alternatively, traditional software such as tutorial and drill and practice software, were described as *full technologies*, where the program's content and strategies are pre-determined. Beichner (1994) examined the cognitive and affective impact of multimedia editing tasks carried out by students near a zoo. The study demonstrated the importance of designing curricula that incorporate realistic, highly involving tasks that empower students to create meaningful multimedia products.

2.4.5 Constructivist use of microcomputer-based laboratories (MBLs)

Microcomputer-based laboratories (MBLs) use sensors and probes to make measurements and allow associated data to be displayed (usually as graphical representations) in real-time on a computer. MBLs enable large amounts of data to be collected and allow for too fast or too slow measurements. They can significantly reduce the time gap between measuring and evaluating the data and help gain more flexible opportunities to plan and realise investigations. For example, students can use their own bodies to make motion graphs (Schecker, 1998).

Russell, Lucas, and McRobbie (1999) looked at the use of constructivist microprocessor-based laboratory activities to facilitate student understanding of physics. In this study, the Grade 11 students worked in pairs on seven POE tasks relating to the subject of Kinematics. In these tasks, the students had to predict the shape of relevant motion graphs before simulating the scenario using the MBL equipment (e.g., motion sensors) and making second-hand observations as they monitored the graphs produced by the MBL equipment. (This use of second-hand data could be seen as contrary to White's (1988) recommendation that POE tasks should consider real situations which allow direct observation!) If there was any discrepancy between their predicted graphs and the computer generated graphs, they were required to explain these differences. Analysis of students' discourse and actions revealed many instances where students negotiated new understandings mediated by the computer activities.

Many studies show that MBLs are beneficial for developing students' graphing skills. For example, Settlage (1995) provided Grade 3 children with light probes in their MBL investigations. In this qualitative study, focussing on an eight week unit in the topic of light, students expanded their skills in graph creation and interpretation and learned graphical literacy as the MBL became a tool to support scientific inquiry.

2.4.6 Constructivist use of modelling, simulations and microworlds

Simulations make a representation of a part of reality, emulating physical systems and processes and allowing experiments that are normally impossible, dangerous, inaccessible, too slow or too fast. As in video-based laboratories, simulations can be reviewed at any time (Rodrigues, 1997) and aid in visualising abstract concepts: "New technologies, such as computer simulations, can help to make the reasoning of children explicit and help them to visualise the consequences of their thinking as they work individually or in small groups" (Plomp & Voogt, 1995, p. 173). Learners can adjust variables and observe effects as they use the simulations to enhance the inquiry process (Windschitl, 2000). Indeed, White (1998) advocates the use of this software to explore and allow students to use the same simulation tools that real scientists encounter.

Modelling systems and microworlds could be considered specific types of simulations. Modelling systems help students to build their own model of reality and gain understanding of complex relations. Microworlds could be described as highly complex simulations where users can explore problems, experiment, test, revise and hypothesise (Weller, 1996). They often use images that represent a concept (semantic icons) which can be directly manipulated by the learner on the screen (e.g., by a mouse click or point etc.) They do not aim to represent reality but are imaginary worlds where students can investigate science problems, hypothesise, design, test their ideas and use feedback to reflect on ideas (Plomp & Voogt, 1995).

Examples of conceptual change studies involving simulations. There have been many studies involving simulations and microworlds in science education which have focussed on conceptual change and problem-solving (Weller, 1996). The following represent a sample of these studies from the physics domain. Flick (1990) allowed 19 sixth grade children to explore Newton's first two laws of motion using a logo simulation game called 'turtle-graphics' that allowed an object to be 'kicked' around towards a target on a frictionless plane. The study found that solving force and motion problems using the simulation enabled some of the students to construct an intuitive understanding of Newton's Laws. Weller (1995) discussed the diagnosis and remediation of three Aristotelian alternative conceptions of force and motion using a computer simulation that focussed on animations of two situations—an object falling off a building and a moving box. He found some evidence of students changing their personal science concepts as they interacted with the simulation. Roth (1995) made a case study of four groups of eleventh grade students using a well known commercial Newtonian microworld called *Interactive Physics*. In this qualitative study, he found that students' science talk progressively converged with canonical ways of talking about the Newtonian microworld (refer to section 2.4.7). Although other positive findings were reported (e.g., the use of the program for teacher demonstrations), the study concluded that the microworld environment was too complex and time-consuming to learn under the normal constraints of a physics course (Roth et al., 1996).

A set of teaching materials developed for the teaching of mechanics in a study by Hennessy et al. (1995) was designed to promote change in learners' understandings of force and motion. A computer simulation was used to encourage 12 to 13 year old students to explore four scenarios involving a cardboard box, a rocket skater, a speedboat and a parachutist. Students could manipulate factors such as friction in their investigations and explore the behaviour and effects of forces; helping them to derive qualitative relationships between relevant variables. The study found that some conceptual change did take place but students displayed the typical tendency to 'hang on' to their preconceptions. The students' ability to distinguish between the real world objects and their representations (within the computer simulation world!) also became an issue in this study. The authors concluded that there is a risk that 'cleaned up' events on a computer could affect the students' perceptions of a computer simulation's credibility.

2.4.7 Peer learning and computers in science education

Peer learning at the computer is an important focus for science education research, particularly studies such as this one that adopt a social constructivist perspective on learning science. In group settings, computer programs can provide a teaching-learning context which can mediate science students' conversations: "...the computer interface becomes a means by which to mediate the teacher's and students' meanings" (Roth, 1995, p. 344). Computer representations are used by practising scientists' to facilitate their group discussions at the computer and hence are an appropriate focus for students' learning conversations in the science classroom. Sample studies from physics education are discussed in this section.

Computer representations as 'conversational artifacts'. Computer representations such as video clips, graphs, photos, diagrams and animations can act as 'conversational artifacts' (Pea, 1993) for learners, providing them with a focus for meaningful peer discussions: "Technologies may play special roles in augmenting learning conversations by representing dynamic concepts (e.g., light rays) that enable the establishment of common attention to referents or coreference among participants in these conversations" (p. 271). The 'surface features' of these representations (such as colour coding, graph labels, lines in a graph) also can support the students' processes of appropriation, negotiation and convergence towards shared understanding (Kozma, 2000). Indeed, real scientists use and discuss representations of nature (or 'inscriptions') in their everyday practice of science: "Much of the work of bringing about new scientific knowledge [by practising scientists] happens in conversations about these inscriptions" (Roth, 1996, p. 173). Hence, as these inscriptions make for a large part of the social organisation of science, they are appropriately used as foci for discussion in science classrooms.

Sample studies. Tao (2000) reported on the use of computer-supported collaborative learning designed to help students develop an understanding of image formation by lenses. The aim of the project was to investigate how students constructed shared knowledge and understanding while working with a multimedia program. The rich qualitative data collected from peer interactions during the study showed that students experienced many instances of conflicts and co-construction that were conducive to the development of understanding. Roth (1996) studied the role of a computer microworld in student's sense-making conversations and found that a Newtonian microworld played an important anchoring role in the coordination of verbal and non-verbal communicative acts and created a context that is shared by students. The microworld served as a "gestural resource" (Roth et al., 1996, p. 1001) to the students' interactions. "Group discussions were facilitated because there was a common focal point, a dynamic image that could be touched, pointed to, and re-presented by hand gestures" (p. 1007). The teacher used the microworld to help students develop from their own familiar ways of talking to more canonical ways of talking.

A study by Cockburn and Greenberg (1995) continued a line of CSCL research (refer to section 2.3.2) that focuses on 'groupware'—software that can facilitate peer collaboration. They investigated a multi-user, networked microworld for the exploration of Newtonian physics. Students in the study were able to alter the attributes of the simulation environment (such as gravity, friction etc.) and manipulate the turtle (position, velocity, mass etc.). There was a strong group awareness feature as several students, collaborating *through* their networked computers, could simultaneously control the microworld and gesture around the shared display using 'telepointers' (on-screen cursors that are continuously visible on all monitors and controlled by each student). In similar findings to the Roth (1995) study, they found that these telepointers provided useful references for learners to point to screen objects, acting as a locus of attention and becoming an artifact that they can talk around: "[Using the telepointers], people can gesture around a shared view, focus attention to settings on the control panels and implicitly indicate both their intent and their action when manipulating a control" (p. 66).

2.4.8 Summary

Technology can support the personal and social meaning making during the knowledge construction process. Students can learn *with* computers rather than *from* computers (Jonassen & Reeves, 1996) in a constructivist learning environment, reflecting on and discussing their views and solving problems in realistic contexts. For example, multimedia programs can provide real-world scenarios for students to consider, helping them to link information to their own experiences. In particular, the use of digital video can expose science students to phenomena normally inaccessible in the classroom and provide students with rich observation experiences. Peer learning environments provide science students with an opportunity to use elements of these computer displays as a focus for consensual meaning-making.

2.5 Conclusion

Constructivist learning theory marks a significant move away from the dominance of behaviourism in science education, emphasising that learners construct their own knowledge, strongly influenced by what they already know. Social constructivists view learning as an inherently social process, using peer discussions as an opportunity to share alternative viewpoints, to challenge others' ideas and help develop alternative points of view. The POE strategy can be used as an instrument to elicit students' views and, like any probe of understanding, also provides students with an opportunity for learning. The collaborative use of computer-mediated POE tasks for these purposes has not been reported in the literature.

Over the past decade, the field of educational technology has endorsed constructivism as a suitable referent for the development and meaningful use of appropriate software in education. Examples in science include the constructivist use of multimedia such as video-based laboratories and student multimedia authoring, microcomputer-based laboratories (MBLs) and microworlds. When used in peer learning environments, students can use representations from these programs as 'conversational artifacts' (Pea, 1993), articulating their own views, reflecting on others' ideas and negotiating shared meanings.

CHAPTER 3

REVIEW OF THE RELATED LITERATURE ON ALTERNATIVE CONCEPTIONS RESEARCH IN MECHANICS

3.0 Overview of chapter

Studies have compared the development of students' science ideas with the evolution of ideas in science through history (Eckstein & Kozhevnikov, 1997; Wandersee, 1986). Indeed, Sequeira and Leite (1991) advocated that science teachers should become acquainted with this important subject to help them anticipate students' alternative ideas, gain some insight on how to deal with these ideas and provide some teaching resources to help students change these ideas. In the light of this research and in the context of this study, the first half of this chapter gives a historical insight into the development of scientific ideas in the domain of mechanics. As well as guiding the design of the predict–observe–explain computer tasks used in the study (refer to chapter 4), this historical perspective will facilitate the analysis of students' views elicited in the study (refer to chapter 7) and also the interpretation of the contemporary literature in this field in the second half of this chapter. The computer program used in this study focuses on vertical motion and projectile motion in a gravitational field. Hence, the research reviewed in this chapter will focus on these two types of motion.

3.1 Introduction

Mechanics is the branch of physics that deals with the movement and interaction of everyday objects. In contrast to other branches of physics, many phenomena in mechanics are visible, and everyday life provides children with many opportunities to observe and interact with related objects. For example, watching sport, riding a bike, throwing a ball, or drawing with a pencil are common everyday experiences with children. These everyday experiences lead to the development of personal, 'naive theories' of motion that provide adequate explanations for what we see and do. According to McCloskey (1983b), "...everyone presumably has some sort of knowledge about motion" (p. 299). People have remarkably well articulated theories of motion, often with consistencies across individuals. These theories or alternative conceptions (also refer to section 2.2.3) are often varieties of pre-Newtonian thinking, are well developed by the age of 9 or 10 years and may not change until formal physics instruction in this area (usually around ages 15 or 16 years), if at all (Eckstein & Shemish, 1989).

Commonsense preconceptions in physics are not arbitrary or trivial; every one of them was argued by pre-Newtonian intellectuals! For example, Halloun and Hestenes (1985b) found many common alternative conceptions held by students were advocated seriously by leading intellectuals from Aristotle to Galileo. Hence, the intellectual struggles of the past give valuable insights into conceptual difficulties of students today.

3.2 Historical perspective

3.2.1 Aristotelian physics

Aristotle's (384–322 BC) dynamics involved both 'natural' and 'violent' (unnatural) motion. Natural motion was an intrinsic property in the moving body, a tendency to move towards its natural place (e.g., at rest). Violent (or unnatural) motion was caused by an external mover that accompanied the body (e.g., another object or a medium such as air). This violent motion only continued while this external agent stayed in contact with the body. According to Aristotle, 'heavy' objects, composed of the elements earth and water, were endowed with the property of gravity—a *tendency* to move towards the centre of the universe. 'Light' objects, composed of the elements air and fire, were endowed with the property of levity—a tendency to rise upwards to flee the centre of the universe (Cohen, 1985).

Aristotle explained the phenomena of objects falling without referring to any external cause (or force). Instead he used the intrinsic tendency of objects to move towards their natural resting place, claiming that the speed of a falling body is proportional to its weight and inversely proportional to the resistance of the medium, implying that objects fall at their own constant speed. This also leads to the belief that heavy objects fall faster. One weakness of this theory was that in a vacuum, a body would fall with infinite speed. Hence, Aristotle argued against the existence of a void or vacuum (Franklin, 1978). To explain objects thrown vertically upward (as in task 2 of this study), Aristotle needed to revert to his theory of unnatural motion. He used the idea of an external mover that overcomes the natural tendency of an object to fall.

Projectile motion posed a real problem for Aristotle: what external force keeps the projectile moving after being launched? Aristotle's classified projectile motion as an unnatural (or 'violent') motion and used the medium (e.g., air) as the external agent of motion. According to Aristotle, a projectile is set in motion due to air pushing at it from behind. The agent of projection gives the medium in contact with the projectile (e.g., air) the 'power of being a mover'; this power is then transmitted to the next layer of air and so on, keeping the projectile in motion until the power gradually dies away.

Plato suggested a similar solution—the process of *antiperistasis* (see Figure 3.1). A projectile at the moment of discharge compresses the air in front of it, which then circulates to the rear of the projectile and pushes it forward, and so on in a vortex.

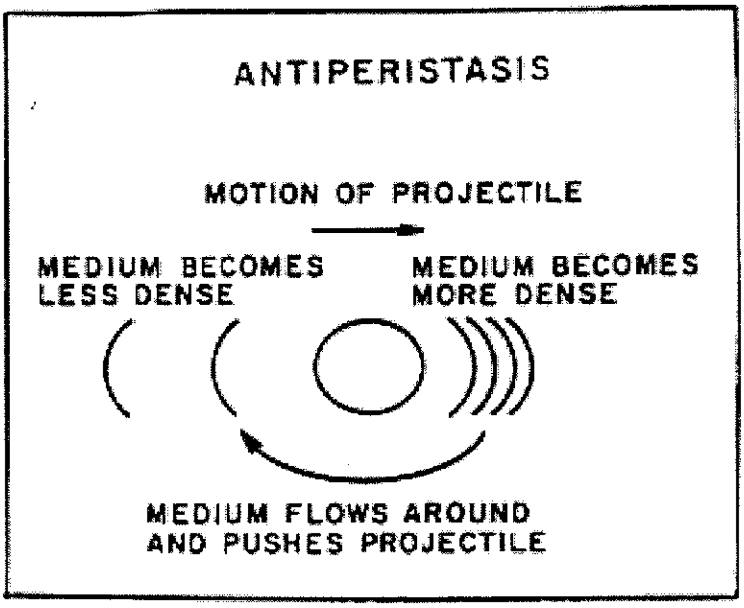


Figure 3.1. Diagram showing the process of Antiperistalsis (from Franklin, 1978, p. 202)

However this reliance on the medium to provide an external agent of motion created another flaw in Aristotelian physics—the medium is used both to sustain and resist motion. This paradox eventually became an 'Achilles' heel' in this theory and medieval theorists began to criticise it (Halloun & Hestenes, 1985b).

3.2.2 Development of medieval impetus theory

In the middle ages many scientists proposed that objects in motion acquire an internal force or *impetus* (in contrast to the emphasis on external forces in Aristotle's violent motion). The idea that a medium was necessary for motion was discarded; indeed the medium only provided a resistance to the motion.

In the 6th century, Johannes Philoponus of Alexandria argued against Aristotelian Physics with his own theory of projectile motion (Franklin, 1978). According to Philoponus, when an object is thrown, the active agent (e.g., the thrower) imparts an 'impressed force' or 'borrowed power' to the projectile itself (rather than the medium surrounding it). It is this impressed force that moves the projectile. The borrowed power will gradually dissipate or die out due to the resistance of the medium and the natural tendency of the body. Avicenna (980–1057 AD) from Arabia supported Philoponus' idea. He proposed the 'mail theory', arguing that a singular impetus could reside in an object at any one time. This force also acted to resist change in the body's state of motion (and persisted indefinitely in a void). Avicenna used this impetus theory to predict the path of both a half and full flight projectile. According to this view, a stone thrown at 45 degrees would acquire an impetus that would cause it to travel along a straight line at a 45-degree elevation until the impetus was exhausted and the stone came momentarily to rest (see Figures 3.2a and 3.2b). The stone's natural gravity would then impart a natural impetus to the stone causing it to fall straight down. Peter Olivi (1245–98) proposed one of the more radical forms of the impetus theory, proposing that the projector sent out 'violent impulses' to the projectile. This action was caused by 'species' and although not transmitted to the projectile by contact or by the medium, it could act from a distance. Francis de Marchia (ca. 1320) also used an internal force argument when he discussed projectile motion as an analogy with a theological problem. Just as a projectile retains its power to move from the projector, so do the sacraments retain a power from God to give grace (Crombie, 1959).

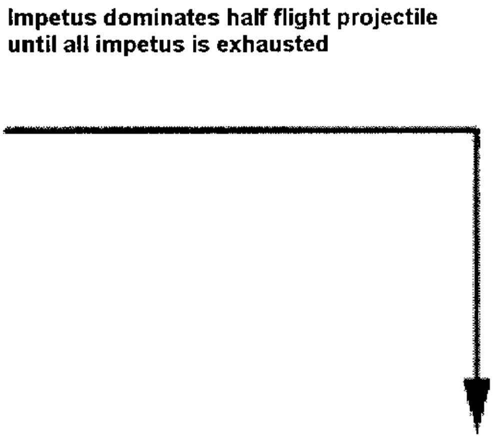


Figure 3.2a. Avicenna's pathway for a half flight projectile

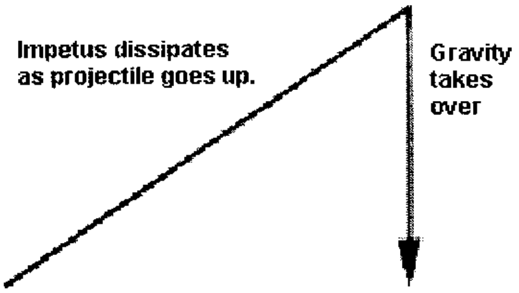


Figure 3.2b. Avicenna's pathway for a full flight projectile

However, John Buridan (1300–1358) is often considered the founder of the medieval impetus theory (Halloun & Hestenes, 1985b; McCloskey, 1983b). His impetus theory was different to deMarchia's impressed force theory as it was permanent, unless acted on by resistances or other forces. He associated impetus with motive power and considered this impetus to be proportional to mass and speed. According to Buridan, a falling body increases its impetus as it gains speed. Natural gravity adds successive increments of impetus during free-fall. Using Buridan's impetus theory, when a body is thrown, the active agent imparts to the object a certain immaterial motive power that sustains the body's motion until it has been dissipated due to resistance by the medium. This also included the concept of 'circular impetus', where an object moving in a circle can retain a tendency to move in a circle, even when the original centripetal force is removed (Franklin, 1978).

Buridan and other medieval theorists believed that projectiles needed to be 'actively' launched (e.g., a throw) to receive impetus from the 'launcher' (e.g., the thrower). Alternatively, 'passively' launched objects from a carrier do not receive any impetus (from the carrier). For example, if an object is (passively) released from a moving carrier such as a train or a plane, Buriden's impetus theory would predict that the object would fall vertically down from the point of release (with no forward movement) as it would not retain any of the carrier's impetus. (For this reason Buridan rejected the theory of a rotating earth. He argued that if an arrow is shot up into the air from a rotating earth (the carrier), it should land somewhere behind where it was launched (if the earth was rotating).

Crombie (1959) pointed out that Albert of Saxony (1316–1390) was a student of Buridan and used impetus theory to explain projectile motion, predicting a three-stage pathway for a half

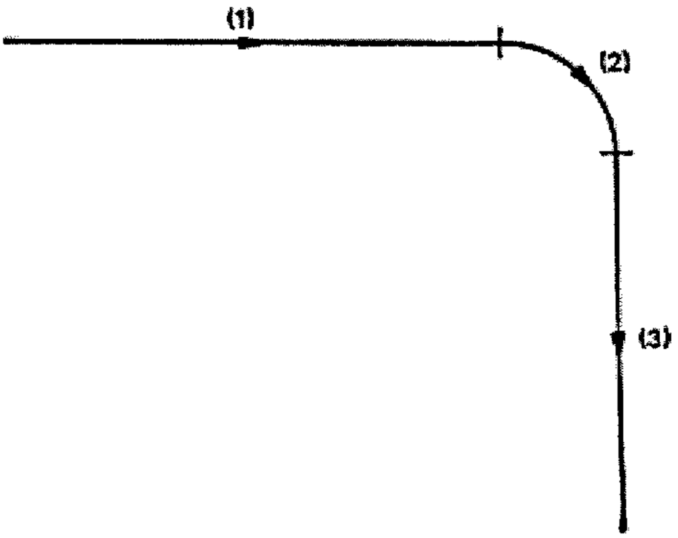


Figure 3.3. Albert of Saxony's pathway for a half flight projectile (from Crombie, 1959, p. 87).

flight projectile. Saxony described stage 1 (see Figure 3.3) of the flight as the 'violent' motion during which the impetus suppresses any effects of gravity and propels the projectile horizontally until it is sufficiently weakened by air resistance. He used the term 'compound impetus' to describe the blend of 'natural' and 'violent' motions in stage 2, in contrast to Avicenna's views. In this stage there is a compromise between the projectile's impetus and its natural heaviness until the initial impetus is exhausted. In stage 3 of the motion, there is pure, natural movement and the projectile falls vertically to the ground. This theory was commonly accepted until the time of Galileo. Figure 3.4 presents a depiction of the full flight version of this theory. Saxony used the same reasoning for a body thrown vertically upwards. Impressed impetus dominates the upward pathway; the object comes to rest at the top where the impetus becomes exhausted; finally, the body falls to the ground as its natural heaviness dominates. Albert of Saxony also advocated the idea of an increasing (rather than a constant) velocity during free-fall (McCloskey, 1983b).

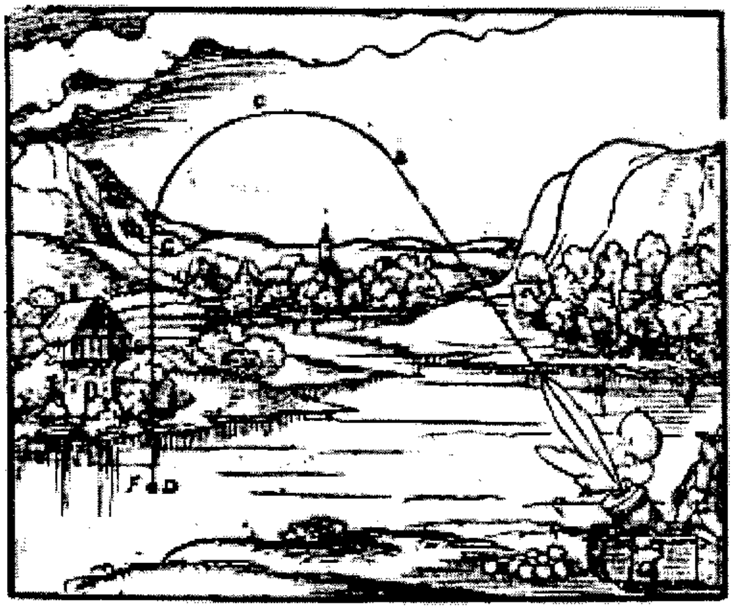


Figure 3.4. This drawing is reproduced from the 1582 edition of *Bawkunst Oder Architectur aller furnemsten*, by Walther Ryff. It illustrates a version of the impetus theory that divides the trajectory of a projectile into three phases. In the first phase, the impetus provided by the canon overpowers the weight of the object and the projectile moves in a straight line. The impetus gradually dissipates and its weight causes the projectile to begin to curve downwards. In the second phase the projectile's movement is influenced by the impetus of the canon and the downward impetus imparted by its weight. In stage 3 the impetus is zero and it falls straight down (from McCloskey, 1983a, p. 114B).

Tartaglia (1500–1557) devoted much time to these problems (Crombie, 1959). He accepted Albert of Saxony's three divisions used to explain half flight projectile motion, but noted that the canon ball fired at an angle began its descent immediately after leaving the gun; concluding that the impetus does not entirely eliminate the object's heaviness property.

3.2.3 Galileo and medieval impetus theory

The early writings of Galileo (1564–1642) indicated a strong and well-articulated impetus theory (Franklin, 1978). He supported the idea that motion is due to the action of a self-expending impressed force, similar to Philiponus and De Marchia. Galileo explained the action of an object thrown vertically upwards (the subject of task 2 in the computer program used in this study) in *Dialogues Concerning Two New Sciences* (1638). In these dialogues, Sagredo plays the role of the 'middleman'; Salviati represents the views of Galileo himself whilst Simplicio's views represent those of Galileo's Aristotelian adversaries.

> Sagredo: ...it seems to me the force impressed by the agent projecting the body upwards diminishes continuously, this force, so long as it was greater than the contrary force of gravitation, impelled the body upwards; when the two are in equilibrium the body ceases to rise and passes through the state of rest in which the impressed impetus is not destroyed but only its excess over the weight off the body has been consumed—the excess which caused the body to rise. Then as the diminution of the outside impetus continues, and gravitation gains the upper hand, the fall begins but slowly at first on account of the opposing impetus, a large portion of which still remains in the body; but as this continues to diminish it also continues to be more and more overcome by gravity, hence the continuous acceleration of motion.
>
> (Galilei, 1991, p. 165)

Based on this argument, as the impressed force continues to decrease, the weight of the body begins to dominate and consequently, the body falls.

Galileo grappled with many 'thought experiments' relating to projectile motion. Many of these were a large influence on the choice of demonstrations in the computer program used in this study. He discussed in detail the problem of the lead ball falling from a moving sailing boat in his publication *Dialogue Concerning Two Chief World Systems* (1632) (This scenario is the subject for task 12 in the computer program used in this study.) Simplicio gives the following hypothesis for the sailing boat problem:

> Simplicio: ...besides which there is the very appropriate experiment of the stone dropped from the top of the mast of a ship, which falls to the foot of the mast when the ship is standing still, but falls as far from that same point when the ship is sailing as the ship is perceived to have advanced during the time of the fall, this being several yards when the ship's course is rapid. (Galilei, 1967, p. 141)

Simplicio offers the following Aristotelian explanation for the simple act of a person throwing a projectile (the subject for task 3 in the computer program used in this study) and Salviati refutes this claim.

> Simplicio. ...Whoever throws the stone has it in his hand; he moves his arm with speed and force; by its motion not only the rock but the surrounding air is moved; the rock, upon being deserted by the hand, finds itself in air which is already moving....
> Salviati. Are you so credulous as to let yourself be persuaded of this nonsense, when you have your own senses to refute it and learn the truth? (Galilei, 1967, p. 151)

One object falling vertically at the same time as another object projected horizontally (the subject for task 13 in the computer program used in this study) was considered by Sagredo:

> Sagredo. ...If a perfectly level cannon on a tower were fired parallel to the horizon, it would not matter whether a small charge or a great one was put in, so that the ball would fall a thousand yards away, or four thousand, or six thousand, or ten thousand or more; all these shots would require equal times, and each time would be equal to that which the ball would have taken in going from the mouth of the canon to the ground if it were allowed to fall straight down....
>
> Salviati. ...I consider it certain that if, when one ball left the cannon, another one were allowed to fall straight down from the same height, they would both arrive on the ground at the same instant, even though the former would have travelled ten thousand yards and the latter a mere hundred.
> (Galilei, 1967, p. 155)

Galileo discussed another 'thought experiment': the horse rider who releases a ball while riding. (This is the subject for tasks 10 and 11 in the computer program used in this study, although in these tasks a person walks forward instead of riding a horse.) After Sagredo introduces the problem, Salviati uses impetus theory to support his observation that the ball indeed does travel forward whilst falling:

> Sagredo. It seems to me that if this motion which the stone shares while on top of the ship's mast were, as you said, conserved in it also after it is separated from the ship, then it would likewise be necessary for a ball dropped to earth by the rider of a galloping horse to continue to follow the horse's path without lagging behind.

...

> Salviati. ...And what difference is there whether the impetus is conferred upon the ball by your hand or by the horse. While you are on horseback, doesn't your hand, and consequently the ball which is in it, move as fast as the ball itself? Hence, upon the mere opening of your hand the ball leaves it with just that much motion already received; not from your own motion of your arm but from the motion dependant on the horse, communicated first to you, then to your arm, and finally to the ball.
> (Galilei, 1967, p. 156)

The related problem of a person riding a horse throwing an object vertically upward also is discussed (and is the subject for task 14 in the computer program used in this study; however a cart and ball is used instead of the horse and javelin). Salviati remarks:

> Salviati. ...And it is folly to say, as some do, that a cavalryman can cast his javelin before him, pursue it on his horse, overtake it and recapture it. I say this is folly because in order to have the projectile return to his hand he would have to throw it straight up, in the same way as if he were standing still. Let the course be what you will, provided that it is uniform; then unless the thing thrown is extremely light, it will fall back into the thrower's hand no matter how high it is thrown.
> (Galilei, 1967, p. 157)

Galileo also considered the angle of launch of a projectile, and the corresponding range values. (This is the subject for task 16 in the program used in this study.) In the *Dialogues Concerning Two New Sciences* (1638), Fourth Day, Galileo showed that the path of a projectile moving with constant horizontal velocity received from a gun and a constant acceleration vertically downwards, was a parabola. He also showed the range of a projectile on a horizontal plane was greatest when the angle of elevation was 45 degrees.

3.2.4 Overview of medieval impetus theory

Medieval impetus theory (or the 'theory of impressed force') was a popular theory used to explain motion phenomena over many centuries. There are some small differences between different versions of impetus theory but all of them postulate two central ideas. Firstly, the act of setting an object in motion impresses on the object an internal force or impetus that serves to maintain the motion (including circular motion). Secondly, the moving body's impetus diminishes over time and eventually comes to a stop. Some impetus theorists held that impetus diminishes spontaneously where as others (e.g., Buridan) argued that external influences such as air resistance are responsible for its loss (Crombie, 1959). When one considers that some of the greatest scientists in history embraced the impetus theory of motion, it is no surprise that students today hold similar alternative conceptions, confusing impetus with Newtonian forces: "The historical comparison makes the high error rates for students on these problems somewhat less surprising" (Clement, 1983, p. 333). The medieval theorists agreed with the general Aristotelian idea that motion must have a cause. The continuous action of a force was thought to be essential to keep an object in motion (a concept Newtonian mechanics explicitly denies). This belief today is often labelled the 'motion implies a force' alternative conception.

3.2.5 Newtonian (classical) physics

Newtonian mechanics is incompatible with the medieval impetus theory in many ways. Newton's first law of motion is that objects move at a steady speed in a straight line, or remain at rest, unless acted upon by an external force. So no force is required to keep an object moving at a constant velocity; in strong contrast to the 'motion implies a force' notion.

The frame of reference is most important in Newtonian physics. A state of rest and a state of uniform constant velocity are considered equivalent in Newtonian mechanics. For example, people on a moving train may consider themselves at rest relative to the other people on the train. However, relative to the reference frame of an observer standing on the ground outside the train, they are moving quickly! In other words, an object travelling at constant speed may be observed as being at rest depending on the frame of reference. This similar treatment of objects at rest and objects moving at constant velocity presents a problem for impetus theorists, as an object needs to be moving to acquire impetus.

A sound understanding of Newton's second law is needed to learn many higher order principles in physics. Basically, the second law is an extension of the first law and associates a force with the *changing* velocity, or acceleration, of an object. Once again, this is in contrast to the pre-Newtonian idea of 'velocity implies a force'.

> In Newton's abstract idealised and frictionless world, the behaviour of objects is vastly different from their behaviour in the Aristotelian world, and the central concept is acceleration not their velocity. (Champagne et al., 1980, p. 1077)

Momentum and impetus. Although impetus was considered to be influenced by mass and speed, Franklin (1978) argued strongly against close correlations between this impetus quantity and the Newtonian 'momentum' quantity. In Newtonian mechanics, momentum is an *effect* of motion and force is a *cause* of motion. However in the 'medieval impetus theory', it is not clear whether impetus is an effect or cause: "...to equate impetus and momentum would be a great anachronism" (Franklin, 1978, p. 205).

Newtonian physics and projectile motion. In the Newtonian world, moving bodies come to rest because external forces (like friction) act to change their speed (or direction). This is in contrast to the naive impetus view that moving bodies simply run out of impetus. For example, a projectile fired horizontally is accelerated downward by the constant force of the earth's gravity. The projectile's horizontal motion is independent of its vertical motion. Ignoring air resistance, there are no external forces in the horizontal direction and hence the horizontal component of the projectile's motion will be constant. This is demonstrated in Figure 3.5, where a ball is projected horizontally at the same time as another ball is released to fall vertically to the earth. Both balls hit the ground at the same time, regardless of their mass. (This particular scenario is the subject of task 12 in the computer program used in this study.)

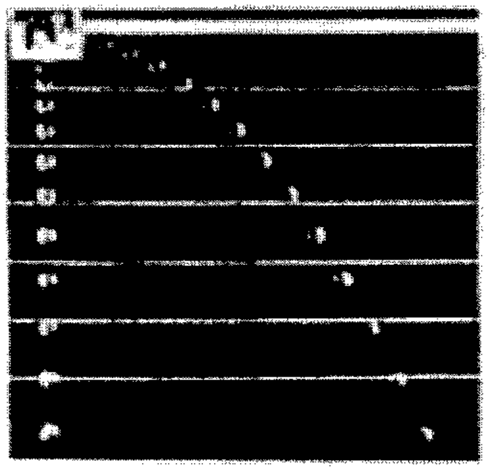


Figure 3.5. Stroboscopic photograph showing the same vertical acceleration for a projectile and a free-falling body (from Eastwell, 1996, p. 314).

Indeed, the action of gravity on a projectile's vertical motion is not delayed by any horizontal impetus. That is, projectile pathways do not continue in a straight line for a time. Rather, the projectile will deviate downwards due to gravity from the moment it is launched. In the case of full flight projectile motion, there is no upward impetus and no upward force as the projectile ascends. There is only the upward component of the projectile's velocity that is steadily reduced by the action of the earth's gravity downward. Furthermore, the peak of the projectile's pathway does not represent a point where upwards and downwards forces are equal as suggested by impetus theorists. Rather, the object is still accelerating downward due to gravity at this point (although it is at rest momentarily).

It is important to note that Newtonian physics is not the end point in the development of knowledge in this domain. For example, Einsteinian mechanics combines the Newtonian properties of gravitational and inertial mass into a single property (just as medieval theorists combined the Aristotelian properties of natural and violent motions into one). However, for the purposes of explaining everyday phenomena in school physics, Newtonian or classical physics is used in this study.

3.2.6 Summary

Aristotle explained vertical motion such as free-falling objects as 'natural motion', referring to a tendency of such objects to move towards their natural resting place. He explained projectile motion as a 'violent motion' caused by the external force of the medium. Medieval impetus theory was developed by various theorists in the middle ages and proposed that objects in motion acquire an internal impetus. For example, it was proposed that this impressed force moved actively launched projectiles (e.g., transferred from the thrower of an object), although passively launched objects would not acquire such impetus!

Galileo used impetus theory in his early writings to help explain many of his famous 'thought experiments'. Modern adaptations of some of these experiments were used as a basis for the development of many of the POE computer tasks used in this study (refer to chapter 4). When one considers that Galileo and other eminent scientists throughout history have embraced the impetus theory of motion, it is hardly surprising that today's science students hold similar alternative conceptions, confusing impetus with Newtonian forces. One basic tenet of all pre-Newtonian theories was that all motion must have a cause. This belief is commonly held by students and is labelled a 'motion implies a force' alternative conception.

3.3 Contemporary studies of students' naive beliefs in the domain of mechanics

Students' alternative conceptions research in the domain of mechanics has flourished, and this was a major reason for choosing the domain of mechanics in this study. Most studies have shown that people of all ages hold some type of intuitive 'motion implies a force' alternative conception (McCloskey, 1983b). Although these preconceptions are often similar to pre-

Newtonian theories, a number of studies (e.g., Halloun & Hestenes, 1985b; Lythcott, 1985) have criticised the automatic labelling of these alternative conceptions as 'Aristotelian'. Halloun and Hestenes (1985b), for example, regard the majority of students' naive beliefs as closer to the medieval impetus theory: "The naive beliefs of students...are sometimes categorised as 'Aristotelian'. The term is inappropriate. The belief systems of most students are closer to the medieval impetus theory..." (p. 1056).

A misunderstanding of technical terms such as *force*, *acceleration*, *momentum*, and *energy* is common, and these terms are often used by students to convey impetus meanings (Fischbein, Stavy, & Ma-Naim, 1989). Indeed, the general confusion surrounding the term *force* can contribute to the development of the 'motion implies a force' misconception (Halloun & Hestenes, 1985a). For example, frictional forces are often not recognised by students (White, 1983), leading to the belief that a continuing force is needed to supply a constant velocity (e.g., pushing an object to keep it moving).

3.3.1 Vertical motion

Viennot (1979) studied students' thinking on motion and concluded that students' often hold simultaneously both Newtonian and non-Newtonian conceptions of force. If the motion is not accessible either through observation or a diagram, the students generally use the correct Newtonian thinking. If the force is opposite to the velocity or the velocity is momentarily zero, students will introduce non-Newtonian forces in the direction of the motion and proportional to the velocity (instead of acceleration).

In a study of university students, Clement (1982) found that many of these students used pre-Newtonian ideas to explain motion situations. For example, he asked students to use vectors to show the forces involved when a coin is tossed vertically into the air. (Task 2 in the computer program used in this study uses a similar scenario of a child throwing a ball vertically upwards.) Figure 3.6 shows some typical results from Clement's (1982) study. One student said that:

> When the coin is on the way up, the force from your hand gradually dies away as it pushes on the coin. On the way up it [the push from your hand] must be greater than gravity otherwise the coin would be moving down. (p. 67)

This 'motion implies a force' alternative conception implies that a change in speed occurs when a force 'dies down' or 'builds up'.

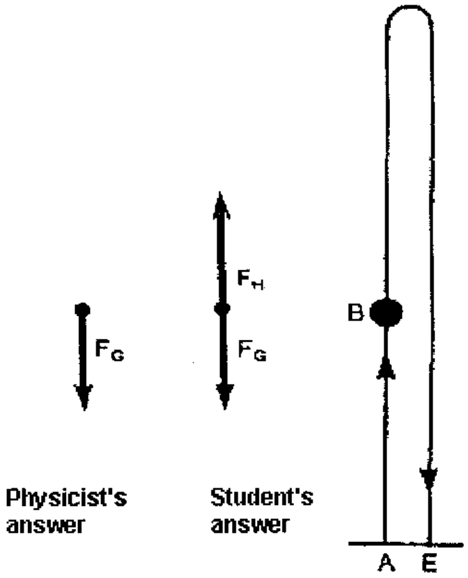


Figure 3.6. Typical responses from students in Clement's (1982) study showing the forces on a coin tossed vertically into the air (p. 67).

Champagne et al. (1980) investigated the pre-instructional conceptions in mechanics held by students in an introductory college physics course. The study once again showed that most students held strong pre-Newtonian ideas. For example, one question probed students' understanding of falling objects. Many students thought that objects fell at a constant speed. Other students had rote learned that objects accelerate, however they reasoned that this was because gravity increases closer to the ground. Many students held the strong view that heavy objects fall faster: "They argued, as Aristotle did, that speed depends only on the weight of the object…" (p. 1078). Indeed, this view that heavy objects fall faster is a highly intuitive one and a common finding in many studies (Driver et al., 1994). (Task 9 from the computer program used in this study focuses on this alternative conception.)

Predict–observe–explain tasks were used by Gunstone and White (1981) to investigate students' thinking about gravity. Common alternative conceptions highlighted by the study were: (1) Gravity diminishes with height. For example, some students thought that the weight of an object on top of a building would change compared to ground level; (2) Gravity is affected by air pressure, temperature and distance from the equator; and (3) There was a widespread misunderstanding of the effects of friction and air resistance. Another study by Minstrell (1982) revealed similar findings.

3.3.2 Projectile motion

Students' ideas relating to projectiles are most important because the scientific account of the motion of a projectile depends critically upon the key insight at the core of the Newtonian framework, the idea of *inertia*. Indeed, projectiles are examples of one important class of moving object–those that continue to move forward for a time after the original applied force ceases to act. Hence, the answers that students give about the motion of projectiles often reflect their thinking about objects in motion generally (Millar & Kragh, 1994).

Whitaker (1983) made a study of college students' views on trajectories and found that many students believed that once the horizontal force (e.g., exerted by the thrower of a ball) is removed, the horizontal velocity ceases abruptly and the body falls vertically down. The students did not think of the horizontal and vertical components of the velocity as being independent. Some students from his study indicated confusion between the terms *speed* and *acceleration* and misused other technical terms such as *gravity*, *momentum* and *force*. Jones (1983) made similar findings with secondary school students. In particular, he found there was a common perception amongst these students that when acceleration is increasing, speed is increasing.

Several variations of the naive impetus theory were observed in a study by Caramazza, McCloskey, and Green (1981). This study with undergraduate students involved predicting pathways for the 'pendulum problem' (see Figure 3.7). This problem involved diagrams

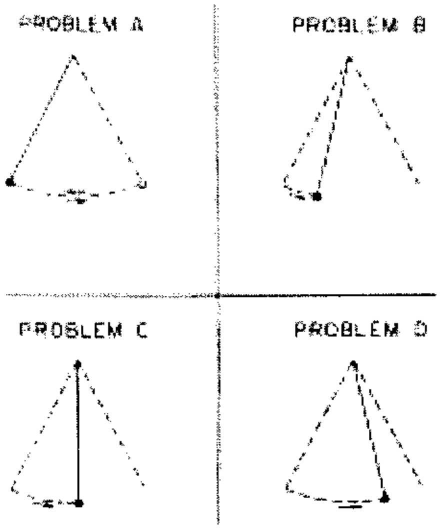


Figure 3.7. Four scenarios given to students in the 'pendulum problem' (from Caramazza et al. 1981, p. 116). (The problem depicted in picture D above became the basis for task 8 in the computer program used in this study.)

showing a metal ball swinging back and forth at the end of a string. Subjects were told that the string was cut at the point shown in the diagram and they were asked to predict the pathway of the ball to the ground after release. Only 25% of all students surveyed gave a correct response to all four questions. For example, in problem C the string is cut as the pendulum bob passes through the equilibrium position (see Figure 3.7). Sixty-five percent of students drew a straight line downwards for their prediction here. Like many other similar studies in this area, the authors concluded that formal instruction had little effect on the students' strong naive conceptions.

McCloskey (1983b) used simple, qualitative problems to probe both high school and college physics students' conceptual understanding. Students were asked to draw predicted pathways for 3 main scenarios: A ball leaving a spiral 'snail track'; a moving plane releasing a bomb (see Figure 3.8); and a ball rolling off a cliff (see Figure 3.9). (Variations of the cliff and ball scenario were used in tasks 4 and 5 from the computer program used in this study.) Most of the subjects said that the body would move forward as it rolled off the table. However, a significant number of students (22%) displayed impetus beliefs, thinking the ball would eventually lose its horizontal motion and fall straight down (see Figure 3.10—diagram C—on the next page). More students displayed an impetus belief with the plane and bomb task. The students seemed to hold a belief that impetus is acquired by a pushed (or rolled) object but not by a carried object. Four versions of popular student beliefs are shown in Figure 3.11 on the next page.

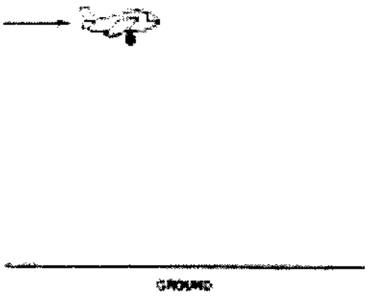


Figure 3.8. Diagram of the aeroplane problem (from McCloskey, 1983b, p. 302).

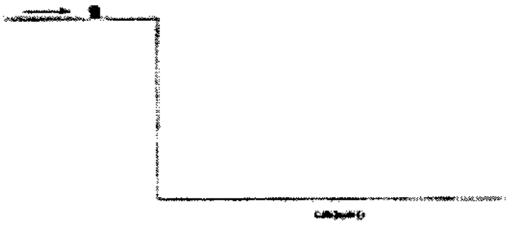


Figure 3.9. Diagram of the cliff problem (from McCloskey, 1983b, p. 304).

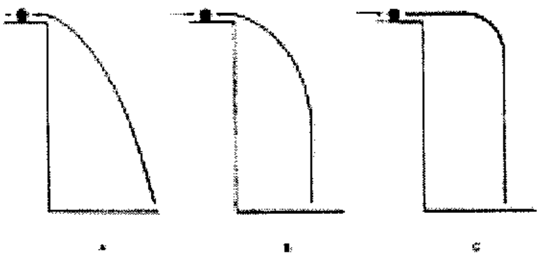


Figure 3.10. Correct response (A) and most common incorrect responses (B and C) for the cliff problem (from McCloskey, 1983b, p. 305). Seventy-four percent of students predicted option A whilst 22% chose either B or C.

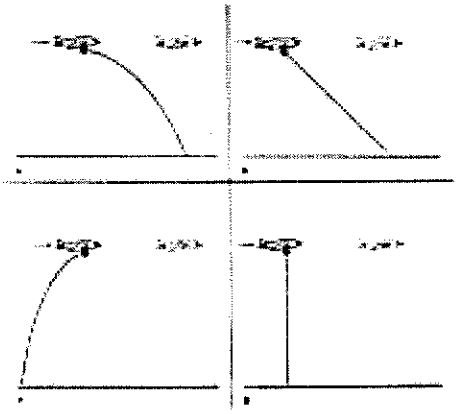


Figure 3.11. Correct response (A) and incorrect responses (B–D) for the plane problem (from McCloskey, 1983b, p. 303). 40% of students predicted option A, 13% chose option B, 11% chose option C and 36% chose option D.

In a related article titled *Intuitive Physics*, McCloskey (1983a) made a detailed discussion of the scenario where a person running at constant speed releases a ball (see Figure 3.12). This scenario is reminiscent of Galileo's 'thought experiment' where he considered a person riding on a horse releasing an object (refer to section 3.2.3). It also is a similar situation to the plane and bomb scenario discussed in McCloskey (1983b). In both situations, a projectile is launched passively from a moving carrier. The author and his colleagues asked college students where the ball would land if it were released by a walking person. Only 45% of students believed the ball would travel forward as it fell. Forty-nine percent thought the ball would fall straight down and 6% thought the ball would go backwards. These results showed that many students believed the act of setting an object in motion impresses on the object an internal force or impetus. More students seemed to believe that impetus is acquired by a pushed object but not by a carried object. These naive theories are common and correspond to pre-Newtonian thinking.

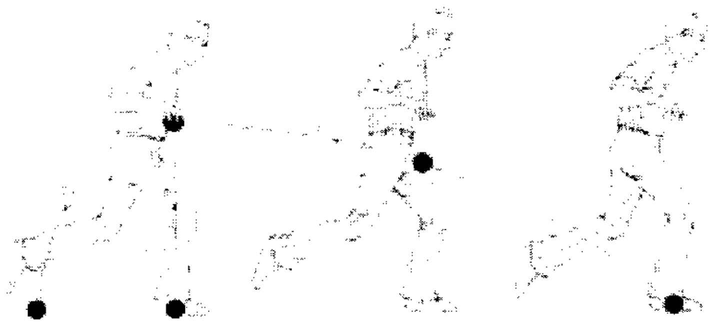


Figure 3.12. Correct response (A) and incorrect responses (B and C) for the running person problem (from McCloskey, 1983a, p. 114A).

In probing into the possible reasons for this common 'straight down belief' for objects released by moving carriers, McCloskey, Washburn, and Felch (1983) isolated confusion over reference frames being a plausible source of this alternative conception: "The motion of the object relative to the moving reference frame may be misperceived as absolute motion" (p. 643). The moving carrier (e.g., a walking person or a moving train) usually stays in view after an object is released and hence may become a frame of reference for the observer. In situations where the air resistance is negligible, the dropped object falls straight down relative to the carrier (assuming the carrier's speed is constant). In situations where the air resistance is noticeable, the dropped object moves backwards relative to the carrier. Of course in both these cases the object moves forwards relative to the ground. To test this perceptual illusion theory, McCloskey et al. (1983) showed a video of a person walking and dropping a ball to a number of subjects. (The film clips were similar to the video clips used in tasks 10 and 11 in the computer program used in this study). Twenty-two percent thought they saw the ball go backwards and 56% thought they saw the ball go down (only 22% said they saw the ball go forward)! They also proposed that films of objects released from carriers might cause frame of reference confusion for students. For example, video shots of bombs or parachutists released from planes are often filmed from the plane itself. From this reference frame (of the carrier), objects appear to fall vertically downward or even backwards in the case of a parachutist. This problem of interpreting reference frames also was discussed by Aguirre (1988). He found that most 15 to 17 year old students think that speed (and the pathway) is an intrinsic property of a moving object independent of any reference frame. The ground was the reference frame implicitly chosen by most students.

In summary, McCloskey (1983b) described variations of students' impetus theory in four main areas. Firstly, the existence of 'curvilinear impetus'. Secondly, the way impetus is dissipated by a moving object. Although some students believe it is self-expending, most believe that impetus is 'sapped' by external forces and influences (e.g., friction, air resistance). Thirdly, the interaction of impetus with gravity. Most students believe that gravity affects a moving object, regardless of the amount of impetus. Some students believe that gravity only affects a moving object after the original impetus falls below a certain critical level. Indeed, this critical level is contentious. Some students think the critical level occurs when the object's impetus becomes less than the gravity. Others believe this level occurs when the impetus becomes zero. This is most pertinent in the case of projectile motion—for example, in the case of a ball rolling off a table. Students holding impetus beliefs would predict that the ball travels in a straight line for a given time after leaving the table, before descending. The point at which the ball begins to descend is the contentious issue. Students who believe that the object's impetus needs to become less than gravity before descending predict a curved path (after an initial horizontal period). Alternatively, students who believe that the object's impetus needs to become zero before descending, predict a longer initial horizontal period before a vertical drop (see Figure 3.10). The fourth and final variation of students' impetus theory relates to how the impetus is imparted. Most students believe that the agent that sets an object in motion imparts an impetus on an object. However, some students believe that the agent must involve a push or a pull to give the object impetus, and hence objects launched by carriers (i.e., passive launches) do not acquire impetus!

Halloun and Hestenes (1985b) conducted a large-scale study involving university science students. They reported that most students held common sense beliefs about motion and force that were incompatible with Newtonian thinking. The students' alternative views were predominantly related to impetus theory (only 17% were classified as holding Newtonian views). As in the Viennot (1979) study, almost all (478) students used a mixture of Aristotelian, impetus and Newtonian theories. Many students had some notion of parabolic motion but few recognised it as a consequence of a constant force. Some students believed that a projectile's motion was not only determined by its initial velocity but also by how that velocity was imparted (e.g., by hand, released by a plane, rolling off a table, etc.) One student's varying predictions for projectiles launched in these different ways is shown in Figure 3.13. (These launch variations mentioned by Halloun and Hestenes (1985b) were a strong influence on the design of the computer program used in this study. For example, task 3 involved a person throwing a projectile. Tasks 4 and 5 involved a ball rolling off a table and tasks 8, 10 and 11 involved passive launches.)

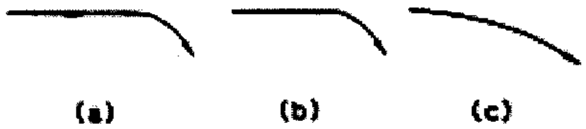


Figure 3.13. Drawings showing a student's predicted pathways for a projectile thrown by hand (a), released from an aeroplane (b), and rolled off a table (c) (from Halloun & Hestenes, 1985b, p. 1062).

There also were many alternative predictions for full flight pathways in the Halloun and Hestenes (1985b) study. The drawings in diagrams (a) and (b) in Figure 3.14 have particular resemblance to the drawings of the 14th century impetus theorists. Halloun and Hestenes (1985b) concluded that conventional instruction involves little meaningful learning and students survive physics courses by rote learning: "They have been forced to cope with the subject by rote memorisation of isolated fragments and by carrying out meaningless tasks" (p. 141).

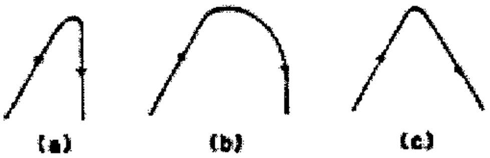


Figure 3.14. Drawings showing common variations of alternative predicted pathways for a full flight projectile (from Halloun & Hestenes, 1985b, p. 1063).

Fischbein et al. (1989) analysed various factors affecting naive impetus interpretations in 10th and 11th grade students. They found that subjects thought the action of impetus depends on the shape, weight and function of the moving body. They also confirmed McCloskey's (1983a) earlier assertion that objects released passively from carriers are considered by many students not to acquire impetus. In contrast, rolled objects and other objects moving on their own will easily acquire impetus, according to these students. They found that most students considered impetus to be a type of 'fuel', similar to that which keeps an engine going.

Students' projectile motion beliefs were investigated amongst children from grades 2 to 12 by Eckstein and Shemesh (1993). A large proportion of younger children held Aristotelian views, such as a firm belief in the 'law of support'. According to this law, falling has an initial cause—namely, a loss of support (Ogborn, 1985). For example, when a ball rolls off a table, many of these children would predict the ball to fall straight down once the support of the table disappears. This finding was different to other studies involving older students (e.g., McCloskey, 1983b) where the Aristotelian 'law of support' responses were minimal. Eckstein and Shemesh (1993) concluded that if teaching strategies are to be effective, the particular 'stage' of the student (Piaget, 1973) should be considered. They extended McCloskey's (1983b) scenario of a ball rolling off a table to a follow up task where a fast ball rolls off a table. The comparison of pathway predictions between the two tasks tended to confirm how firmly the children held on to their naive pre-Newtonian beliefs. (The same idea was incorporated into the computer program used in this study and became the subject for tasks 4 and 5.)

More recently, Eckstein and Kozhevnikov (1997) studied the development of children's conceptions relating to projectile motion and compared these beliefs with the historical development of projectile motion theories. They found that the development of children's beliefs proceeds in stages, with the concepts in each stage parallel to a corresponding historical stage. One of their conclusions was that educators could learn something from the implicit wisdom of children who spontaneously developed scientifically acceptable concepts.

Thirty-six school aged students aged between 10 and 15 years were interviewed in relation to several scenarios relating to force and motion in a study by Twigger et al. (1994). In one of the projectile motion tasks, students were asked about a girl throwing a ball up in the air at an angle to produce projectile motion. The researchers found that 75% of students displayed a lack of 'speed symmetry', believing that the ball would come down faster than its upward journey. Seventy-five percent of students also believed the ball would gain speed after it left the girl's hand. Many students displayed typical impetus beliefs. Fifty percent of students thought that the ball would run out of energy as it slowed down on the upward stage of the flight and 32% thought that the ball would 'run out of force' at this same stage. However, they found no age trends amongst the students.

Millar and Kragh (1994) investigated 11-year-old students' thoughts on projectile motion, particularly any differences due to the way the projectile is launched. Like the McCloskey (1983b) study, it was common for children to think that a passively launched projectile from a carrier (e.g., dropping an object out of the window of a moving car) does not possess forward velocity when it is released. Many children from this study believed that a passively launched projectile would move backwards when released. Students' reasons implied a confusion between the reference frame of the carrier and that of the ground. From the reference frame of the car, objects do appear to be blown backwards, as discussed by McCloskey et al. (1983). Another possible reason was the notion that a moving carrier creates wind around it that acts to blow things in the opposite direction. Unlike air resistance, which opposes motion, this air movement was a cause of motion for these students! Millar and Kragh (1994) labelled this belief as the 'reverse theory' and found that children used it especially when dealing with less massive objects. Children's answers were strongly influenced by details of the situation. For example, the speed of the carrier, the weight of the projectile (see Figure 3.15), and especially air resistance were crucial for the subjects. (The weight variations used in the 'runner scenario' shown in Figure 3.15 became a large influence on the design of tasks 10 and 11 in the computer program used in this study. The mass of the projectile is the key variable that changes significantly between each of these tasks.) They concluded that there were three categories of students' predictions about the motion of a projectile dropped from a carrier. Firstly, the projectile moves forward in the direction of the carrier (forward velocity response). Secondly, the projectile moves neither forward nor back but falls straight down (zero velocity response). This same phenomenon was labelled the 'straight down belief' by McCloskey (1983b). Thirdly, the projectile moves backwards in the opposite direction to the carrier (reverse velocity response).

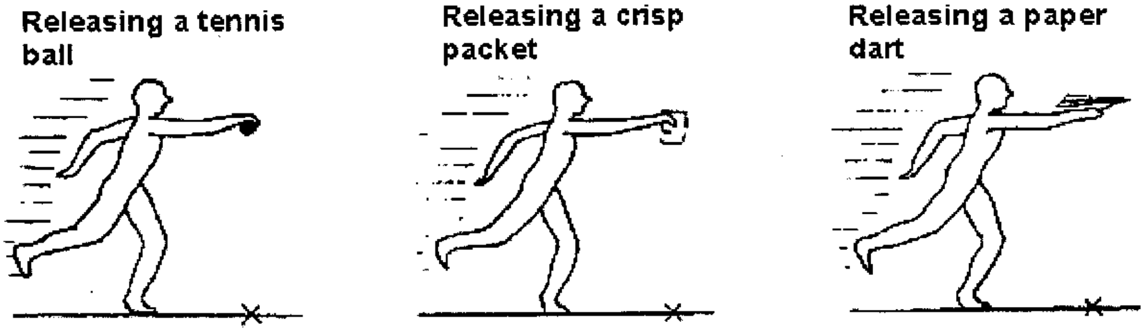


Figure 3.15. One of the contexts given to students in the Millar and Kragh (1994) study. Students were asked to consider a runner releasing a tennis ball (a), a crisp packet (b) and a paper dart (c) (from Millar & Kragh, 1994, p. 29).

3.3.3 Misuse of technical terms

A lack of understanding of physics terms, which is common amongst introductory physics students, impedes a full understanding of physics concepts (also refer to section 2.2.2). For example, a general confusion of the term *force* is common (Driver et al., 1994; Osborne & Freyberg, 1985), contributing to the development of a 'motion implies a force' misconception (Halloun & Hestenes, 1985a).

Osborne (1984) discussed the importance of language in the development of a person's 'lay dynamics beliefs'. These personal science views are influenced by "the form and content of the language a child grows up to speak and the accounts and images of experiences conveyed by those with whom the child comes in contact, the media and the authors of books he or she reads" (p. 506). The use of (Newtonian) words such as *momentum* and *inertia* are good examples of students using a distorted impetus theory to explain phenomena. McCloskey (1983b) notes that students often use the word *momentum* as another term for impetus. The term *momentum* is often used by students in the context of imparting or 'impressing' impetus on an object. Many other studies (e.g., McDermott, 1984; Whitaker, 1983) also discussed this misuse of the word *momentum*. A misunderstanding of other technical terms such as *force*, *acceleration*, and *energy* also is common and can be used by students to convey impetus meanings (Fischbein et al., 1989).

Teachers and students need to take great care with their use of language in the science classroom (McDermott, 1984). Words such as *force*, *acceleration* and *momentum* have a meaning in physics different from their everyday meaning. Use of such terms often shows a lack of understanding of their meanings: "...it is important to ascertain what a student actually means when he uses, or understands when he hears, a technical word" (p. 28).

3.3.4 Summary

Students' personal science views of motion are a natural outcome of experience with moving objects in the real world: "...people develop on the basis of their everyday experience remarkably well articulated naive theories of motion" (McCloskey, 1983b, p. 299). For example, the simple act of catching a ball means that children have formulated (sometimes unconsciously) a basic theory of projectile motion: "A child requires a theory about projectile motion if he or she is to successfully catch a ball, but it may be a theory he or she is quite unconscious of..." (Osborne, 1984, p. 505).

Many students hold a strong 'naive theory of motion' that has strong correlations to impetus theory (McCloskey, 1983b). Acceleration does not hold a central role in this common sense belief system (McDermott, 1984). This 'motion implies a force' theory used by students can be summarised as follows: (1) The act of setting an object in motion imparts to the object an *internal* force (or impetus) that maintains the motion and (2) A moving object's internal force (or impetus) dissipates either spontaneously or as a result of external forces. Hence, the object either slows or stops. (i.e., A state of rest implies the absence of impetus; a state of motion implies the presence of impetus.)

Information presented in the classroom may be misrepresented or distorted to fit students' personal views and many students emerge from their physics instruction with their impetus theories intact.

3.4 Conclusion

Scientists have struggled with basic ideas relating to force and motion for centuries. Brilliant theorists from Aristotle to Newton grappled with basic laws of free fall and projectile motion and hence it is no surprise that today's physics students hold strong alternative conceptions in this domain.

> If the evaluation of common sense was so difficult for the intellectual giants from Aristotle to Galileo, we should not be surprised to find that it is a problem for ordinary students today. (Halloun & Hestenes, 1985b, p. 1056)

Indeed, the 'thought experiments' documented and considered by these scientists (e.g., in Galileo's *Dialogues Concerning Two New Sciences* (1638)) provide wonderful scenarios for today's students to consider (Sequira et al., 1991). Their thoughts and responses to such problems (set in a modern context) can provide insight into their own naive views of motion. Although young children can show variations of Aristotelian beliefs (such as the 'law of support'), many students have developed a strong 'motion implies a force' belief by the ages of 9 or 10. A misunderstanding of technical terms contributes to the development of alternative conceptions and students will often use variations of impetus theory to explain force and motion phenomena.

CHAPTER 4
DESIGN AND DEVELOPMENT OF COMPUTER PROGRAM USED IN THIS STUDY

4.0 Overview of chapter

This chapter outlines how constructivism and related literature from both the science education and educational technology fields informed the design and development of the computer program used in this study. This discussion will facilitate a full understanding of methodology issues in chapter 5 and provide a more transparent insight into the study's findings and conclusions presented in chapters 6 to 9.

The program was created by the author over a six-month period in the early stages of the study's evolution. Formative evaluations proceeded using one physics class and three senior university academics over a further four-month period before the program was ready to be used in the study. The final program essentially consisted of 16 computer-mediated predict–observe–explain tasks designed to act as a probe of students' pre-instructional physics views in the domain of mechanics (refer to Appendix A for sample screen shots from each task). Like other instruments designed to elicit students' views (e.g., multiple-choice tests, concept maps), the program also offered students an opportunity to learn. Unlike many other probes of understanding, it was designed to be used in a collaborative setting, giving students a chance to negotiate meaning together. These multimedia-supported POE tasks represent a new development in the use of the POE strategy in science education. (NB. Unless otherwise indicated, descriptions of tasks and screen-shots presented in this chapter relate to the final version of the program used in this study.)

4.1 Constructivism and educational software design

Guidelines for educational software design have traditionally adopted a transmissive view of instruction derived from behaviourist and information-processing learning theories (Greening, 1998; Willis, 2000). Software designed under an objectivist paradigm (refer to section 2.1) tends to view the learner as a passive recipient of instruction: "Interactive multimedia based on instructivist pedagogy generally treats learners as empty vessels to be filled with knowledge" (Reeves & Harmon, 1994, p. 477). These types of computer-based environments are usually designed for individual students working separately on computers and there has been an associated tendency for software developers to ignore group learning goals in these designs (Oliver, Omari, & Herrington, 1998).

However, there has recently been a noticeable shift of emphasis from these popular behaviourist instructional designs to a constructivist view (refer to section 2.2) of software design. Indeed, the term *educational design* has been preferred by authors such as Phillips (1997) to move away from the objectivist connotations of the term *instructional design*. Willis (2000) emphasised that any software design guidelines based on constructivism need to be sympathetic to the 'multiple perspectives' aspect of this paradigm. Hence he advocates general guiding principles for constructivist software design (rather than specific, prescriptive 'how-to' rules), open to different specific interpretations according to the designer's context. He also promotes the close involvement of the user in the design process whereby learners can play a critical role in designing the program. This is in contrast to traditional 'expert' design processes where user input is minimal.

Educational software designed from constructivist principles should encourage the construction of learning environments that provide multiple representations of reality, avoid oversimplification by representing the natural complexity of the world and provide real-world, case-based learning environments:

> Constructivists tend to favour problem-solving exercises that are linked to student interests, that have at least some of the 'messy' attributes of real world problems and that are meaningful and satisfying for students to solve. (Lebow, 1993, p. 9)

A common guiding principle for the development of constructivist software is that these programs need to support students' collaborative construction of knowledge in meaningful *authentic* environments (Duffy & Cunningham, 1996; Greening, 1998; Harper & Hedberg, 1997; Jonassen, 1994). For example, Squires (1999) suggests that constructivist software should allow for *cognitive authenticity* by promoting opportunities for learners to express personal ideas and opinions and articulate ideas, experiment with ideas, engage in complex environments which are representative of interesting and motivating tasks and receive opportunities for intrinsic feedback. He also suggests that constructivist software should allow for *contextual authenticity* by relating tasks to the real world, encouraging collaborative learning in which peer group discussion is prominent and encouraging the role of a teacher as a facilitator of learning.

Social constructivism (refer to section 2.2.2) is an important perspective in many of these general guidelines. From this perspective, software needs to promote and foster social environments that support collaborative construction of knowledge through social negotiation and reflection (Greening, 1998; Lin et al., 1999). Students need opportunities to submit their own (or jointly constructed) ideas to empirical evidence and reformulate them if necessary. Collaboration is obviously a key here as students' ideas are constructed, debated and reformulated just like in the real scientific process (Kelly & Crawford, 1996). Teachers also need to allow time for reflection, debriefing and whole class sharing of ideas and experiences.

4.2 Computer program used in this study

The final program used in this study comprised 16 multimedia-supported POE tasks designed to elicit students' pre-instructional physics views (refer to Appendix A for sample screen shots). The program was designed to be used collaboratively to initiate articulation of students' ideas, reflection and consensual meaning making and foster a social constructivist learning environment. The computer environment facilitates a move away from traditional whole class demonstrations, provides a suitable scaffold for the POE strategy and supports the use of the digital video medium to present interesting contexts. Science education literature informed the challenging process of selecting and creating the digital video clips used in the computer-mediated POE tasks whilst alternative conceptions research informed the multiple-choice options offered in the prediction stage of the tasks.

4.2.1 Rationale

The elicitation of students' pre-instructional views is a key strategy in any teaching approach informed by constructivism (Driver & Scott, 1996). The program used in this study is designed to use the well-known predict–observe–explain strategy (refer to section 2.2.4) in a computer-mediated environment to elicit students' science views. Hence the program offers an alternative to other 'diagnostic instruments' such as student interviews, multiple-choice tests and concept maps. However, the process of eliciting student ideas can also offer students an opportunity for learning (Duit & Confrey, 1996). Indeed, the POE strategy is more than a probe of student understanding. It has the potential to help students explore and justify their own individual ideas, especially in the prediction and reasoning stages. If the observation phase of the POE task provides some conflict with the student's earlier prediction, reconstruction and revision of initial ideas is possible during the explanation stage.

This program is designed to be used by students in collaborative pairs (refer to section 5.7.3 for further rationale for use of pairs). This is a significant change from the use of other 'probes of understanding' used in most studies found in the literature. For example, interviews, diagnostic multiple-choice tests and student journals are usually completed individually (Duit et al., 1996). By using this computer 'probe' in pairs, obviously ideas elicited and documented by the computer program are not necessarily an individual's views and indeed may be socially mediated ideas (within the small groups). Hence the detail of individual student's preconceptions is somewhat diminished by allowing the students to work in collaborative pairs. However, most teachers in the busy world of the average science classroom do not have time to read and analyse individual results of these formative assessment tasks. More importantly, the collaborative use of the program gives students the opportunity to reflect on their own and others' ideas and construct meaning in a social setting, an important part of a social constructivist perspective on learning (Prawat, 1993; Solomon, 1987).

4.2.2 Aims of the program

Cognitive learning outcomes for students. The program is designed to elicit and promote discussion about students' pre-instructional physics conceptions. The collaborative use of the POE computer tasks is designed to facilitate these peer discussions and promote conceptual development and consensual meaning-making in the domain of physics by one or more of the following:

a) articulation and justification of a student's own ideas
b) reflection on the viability of other students' ideas
c) critical reflection on a student's own ideas
d) construction and negotiation of new ideas

The program also provides students with an opportunity to engage in 'science talk' (Lemke, 1990) and a means of developing science discourse skills (e.g., exploration, justification, negotiation, challenge).

Affective learning outcomes for students. The challenging, real world contexts presented in the program are designed to stimulate students' intrinsic interest and curiosity in various physics events and related principles. Hence the program fosters student awareness and appreciation of the integral relationship between physics and students' everyday lives.

Benefits for instructor – an instrument to probe understanding. The computer program acts as a diagnostic instrument for probing students' conceptual understanding; documenting the elicited views of the students in text files on the computer hard drive. Hence results can be used to guide future learning episodes (Ausubel, 1968). Unlike traditional whole class, instructor-led demonstrations, the computer-mediated POE tasks provide an opportunity for the teacher to engage in small group discussions with students. The program may also provide a stimulus for later whole class discussions.

4.2.3 Description of computer-mediated POE tasks

The program was developed by the author during 1998 using the multimedia authoring software: Macromedia© Authorware. The final program makes use of 16 digital video clips of appropriate physics demonstrations, each embedded in their own POE sequence (see Table 4.1 for brief description of each task). The video demonstrations depict scenarios that present real world contexts to the students, although a few feature laboratory equipment that would be difficult or time consuming to set up. Each POE task requires students to consider a scenario and commit themselves to a prediction and reason for a particular outcome, before observing the video clip and explaining any discrepancies between their predictions and observations. Instead of observing real life demonstrations (traditionally conducted by the teacher in a whole class setting) in the observation phase of the POE sequence, students collaborate in small groups at the computer to make detailed qualitative observations of the video-based demonstrations. These observations provide the intrinsic feedback on their earlier predictions.

Where the outcomes of the demonstrations are limited, students make their predictions using a multiple-choice format. When pathway predictions are needed, students make drawings for both their predictions and observations. Reasons for predictions, observations and explanations are required to be typed using full sentences (see screen shots in Figures 4.1 to 4.6). All multiple choice selections and written responses were recorded on the computer as text files (refer to Appendix B for sample).

4.2.4 Domain of program and syllabus links

The topic of motion (mainly projectile motion) was chosen as the domain for the program for three main reasons. Firstly, there was ample literature on student alternative conceptions in mechanics to aid construction of the POE tasks as well as for use in analyses of students' elicited preconceptions. Secondly, motion is an essential part of all introductory physics courses. For example, motion is a focus of the core module *Moving About* in the preliminary stage 6 physics course in NSW Australia (see NSW Board of Studies, 2001, p. 35). Indeed, projectile motion is a focus of the core module *Space* in the HSC stage 6 physics course (see NSW Board of Studies, 2001, p. 49). Thirdly, there are many possible demonstrations that depict various forms of motion that are relatively easy to create and observe on film.

Three video clips (tasks 1, 2 and 9) related to vertical motion only and were designed to elicit alternative viewpoints relating to one-dimensional motion. The remaining videos covered both half flight and full flight projectile motion. Projectiles

Table 4.1
Description of the final 16 POE computer tasks and their relationship with the physics education literature

Task Number & Name	Motion Type (Type of Launch)	Description (from Introduction Screen)	Prediction Question and Given Options (from Second Screen)	Sample Related Literature
1. Falling Ball	Vertical (Passive)	The child in the photo is holding a ball. She is about to release the ball so it will fall.	What happens to the motion of the ball as it falls? a) It will get faster. b) It will slow down. c) It will fall at a constant speed. d) Other.	Champagne et al., 1980; Driver et al., 1994, pp. 163–165; Halloun & Hestenes, 1985a, p. 1049; Hestenes, Wells, & Swackhamer, 1992, p. 156.
2. Rising Ball	Vertical (Active)	The child in the photo is holding a ball. She is about to throw the ball upwards.	What happens to the motion of the ball as it rises upwards? a) It will get faster as it rises. b) It will slow down as it rises. c) It will rise at a constant speed. d) Other.	Clement, 1982, p. 67; Driver et al., 1994 pp. 163–165; Enderstein & Spargo, 1996, p. 470; Halloun & Hestenes, 1985a, p. 1049; McDermott, 1984, p. 30.
3. Ball Throw	Half Flight Projectile (Active)	A tennis ball is about to be thrown by a person from left to right. The ball will initially be thrown horizontally as shown by the green arrow in the photo.	What is the shape of the pathway that the ball follows while it is in the air? *Paper drawing required.*	Eckstein et al., 1997, p. 1065; Halloun & Hestenes, 1985b, p. 1058, 1062; Hestenes et al., 1992, p. 156; McCloskey, 1983a, p. 116; McCloskey, 1983b, p. 305.
4. Slow Ball Jump	Half Flight Projectile (Active)	A tennis ball is about to roll off the table as shown in the photo. The ball is travelling SLOWLY from left to right. *Note*: The projectile is launched in a different way from task 3.	What is the shape of the pathway that the SLOW ball follows while it is in the air? *Paper drawing required.*	Eckstein et al., 1997, p. 1065; Halloun & Hestenes, 1985a, p. 1051; Halloun & Hestenes, 1985b, p. 1058; Hestenes et al., 1992, p. 156; McCloskey, 1983a, p116; McCloskey, 1983b, p. 305.
5. Fast Ball Jump	Half Flight Projectile (Active)	A tennis ball is about to roll off the table as shown in the photo. The ball is travelling FAST from left to right. *Note*: The velocity of the projectile has increased from task 4.	What is the shape of the pathway that the FAST ball follows while it is in the air? *Paper drawing required.*	Eckstein et al., 1997, p. 1065; Halloun & Hestenes, 1985a, p. 1051; Halloun & Hestenes, 1985b, p. 1058; Hestenes et al., 1992, p. 156; McCloskey, 1983a, p. 116; McCloskey, 1983b, p. 305.
6. Car Launch	Half Flight Projectile (Active)	The HEAVY car in the photo is about to be driven off the cliff while travelling quite fast. It is travelling from left to right. The cliff is approximately 20m high. *Note*: The mass of the projectile has increased from tasks 4 and 5.	What is the shape of the pathway that the HEAVY car follows while it is in the air? *Paper drawing required.*	Eckstein et al., 1997, p. 1065; Halloun & Hestenes, 1985a, p. 1051; Halloun & Hestenes, 1985b, p. 1058; Hestenes et al., 1992, p. 156; McCloskey, 1983a, p. 116; McCloskey, 1983b, p. 305.
7. Soccer Ball	Full Flight Projectile (Active)	The soccer ball in the photo is about to be kicked downfield (from left to right on your screen) by a soccer player. The ball will travel through the air (not along the ground).	What is the shape of the pathway that the soccer ball follows while it is in the air? *Paper drawing required.*	Halloun & Hestenes, 1985b, p. 1063; McCloskey, 1983a, p114B; McCloskey, 1983b, p. 308.
8. Ball and Swing	Half-Full Flight Projectile (Passive)	The person is riding on a swing. He is holding a tennis ball in his outstretched hand. On the next swing forward, the boy will release the ball (while continuing to move forward on the swing) at the point marked 'X' on the screen, just BEFORE he reaches his maximum height.	What is the shape of the pathway that the ball follows while it is in the air (after the boy releases it)? *Paper drawing required.*	Caramazza et al., 1981, p. 117; McCloskey, 1983b, p. 311.

Table 4.1 (continued)
Description of the final 16 POE computer tasks and their relationship with the physics education literature

Task Number & Name	Motion Type (Type of Launch)	Description (from Introduction Screen)	Prediction Question and Given Options (from Second Screen)	Sample Related Literature
9. The Astronaut	Vertical (Passive)	The astronaut in the photo is on the moon. He has a hammer in his right hand and a feather in his left hand and will release both objects at the same time. Both objects are held at the same height above the moon's surface.	Which object will hit the moon's surface first? a) The feather. b) The hammer. c) Both at the same time.	Clement, 1982, p. 67; Driver et al., 1994, pp. 163–165; Enderstein et al., 1996, p. 470; Halloun & Hestenes, 1985a, p. 1049; McDermott, 1984, p. 30.
10. Heavy Ball and Cup	Half Flight Projectile (Passive)	The student is walking at a constant pace from left to right. There is a cup placed on the ground ahead of her. She has a HEAVY ball in her hand and will release it (while walking) when her hand is directly above the cup.	Where will the HEAVY ball land? a) It will land behind the cup (at A). b) It will land in the cup (at B). c) It will land in front of the cup (at C).	Fischbein et al., 1989, p. 71; Halloun & Hestenes, 1985b, p. 1062; Hestenes et al., 1992, p. 157; McCloskey, 1983a, p. 114A & p. 122; McCloskey, 1983b, p. 303.
11. Light Ball and Cup	Half Flight Projectile (Passive)	The student is walking at a constant pace from left to right. There is a cup placed on the ground ahead of her. She has a LIGHT ball in her hand and will release it (while walking) when her hand is directly above the cup. *Note*: The mass has decreased from task 10.	Where will the LIGHT ball land? a) It will land behind the cup (at A). b) It will land in the cup (at B). c) It will land in front of the cup (at C).	Fischbein et al., 1989, p. 71; Halloun & Hestenes, 1985b, p. 1062; Hestenes et al., 1992, p. 157; McCloskey, 1983a, p. 114A & p. 122; McCloskey, 1983b, p. 303.
12. Sailing Boat	Half Flight Projectile (Passive)	The boat in the photo is moving from left to right at a constant speed. There is a ball attached to the top of the mast. The ball will be released and fall while the boat continues to move with the same speed.	Where (on the moving boat) will the ball land after it falls? a) It will land to the left of the mast (at A). b) It will land directly below the mast (at B). c) It will land to the right of the mast (at C).	Hestenes et al., 1992, p. 156; McCloskey, 1983a, p114A, 122; Millar & Kragh, 1994, p. 29.
13. Falling Balls	Half Flight Projectile (Active)	The two balls in the photo are at the same height above the ground. They will be released at the same time. The ball on the left will be launched horizontally to the left. The ball on the right will be released from rest and fall vertically down.	Which ball will hit the ground first? a)The ball on the left. b) The ball on the right. c) Both will land at the same time.	Halloun & Hestenes, 1985a, p. 1052; McCloskey, 1983a, p. 116.
14. Cart and Ball I	Full Flight Projectile (Active)	The cart is moving horizontally from left to right at a constant speed. There is a small ball in the tube at the centre of the cart. The ball is about to be launched vertically upwards out of the tube (while the cart continues to move at the same speed to the right).	Where will the ball land? a) To the left of the cart. b) To the right of the cart. c) Back in the cart.	Millar & Kragh, 1994, p. 28.
15. Cart and Ball II	Half-Full Flight Projectile (Active)	The cart is 'falling' under gravity from left to right down the slope. There is a small ball in the tube at the centre of the cart. The ball is about to be launched out of the tube (while the cart continues to move down the slope).	Where will the ball land? a) To the left of the cart. b) To the right of the cart. c) Back in the cart.	
16. The Hose	Full Flight Projectile (Active)	The person in the photo is holding a hose. In photo A, the hose is held between 0 and 30 degrees to the horizontal. In photo B, 30 to 60 degrees. In photo C, 60 to 90 degrees.	What angle will produce the largest horizontal range of the water? a) 0 to 30 degrees. b) 30 to 60 degrees. c) 60 to 90 degrees.	

used in these video clips covered both active launches (e.g., a person throwing a ball in task 3) and passive launches from carriers (Millar & Kragh, 1994).

4.2.5 Rationale for using computer-mediated POE tasks incorporating the use of digital video clips

There were three key reasons for using POE tasks embedded in a multimedia computer program. These reasons are aligned with general guidelines on the constructivist design of educational software (refer to section 4.1).

Firstly, the computer environment represents a move away from traditional whole class demonstrations and permits more intimate, small group interactions, giving students control of the demonstrations and allowing the teacher more time to interact with students. These collaborative small groups can encourage the social interactions and personal reflections which are essential for peer learning in a social constructivist environment.

Secondly, the computer environment can scaffold the sequencing and presentation of the POE tasks. For example, the program used in this study does not allow the students to view the video of a demonstration (the observation phase) until their predictions and reasons are completed. (Indeed, it is not possible to change these responses after viewing the video clip.) The computer program can also automatically and efficiently places students' written responses into a text file for further analysis.

Thirdly, the computer environment can support the use of the digital video medium to present the physical scenarios that are the focus of the POE tasks. In terms of the POE strategy, the use of digital video clips can provide students with elaborate feedback on their predictions. The digital video clips can also provide realistic contexts for the students to consider, showing dangerous, difficult, expensive or time-consuming demonstrations not normally possible in the classroom (see section 2.4.4). These complex but realistic contexts can contribute to the meaningful authentic environment discussed by Squires (1999) and encourage discussion and reflection on prior experiences (Escalada & Zollman, 1997).

An important learning outcome in most science courses is for students to learn to observe their own world more carefully. The use of digital video gives teachers and students sophisticated tools to observe dynamic processes and physical phenomena in intricate detail. The ability to slow down time (using slow motion or step-frame facilities) and replay exact replications of demonstrations (refer to section 2.4.4) makes the video medium most suitable for students to observe and consider time-dependant phenomena prevalent in many science episodes, particularly in the physics domain of mechanics. Techniques such as time-lapse and stroboscopic photography also become possible and allow students to observe a wider range of physical phenomena. Most introductory physics courses recognise these affordances and promote the use of the video medium:

> Practical experiences [in the NSW preliminary and HSC physics course] should emphasise hands-on activities, including…the use of animation, video and film resources that can be used to capture/obtain information not available in other forms. (NSW Board of Studies, 2001, p. 9)

4.2.6 The program's links to past uses of video in physics learning

The use of video and films as visual aids in physics education dates back to the 1950's when the American Association of Physics Teachers sponsored a set of films to bring together current film technology, the expertise of the film producer and the knowledge and experience of outstanding physics teachers. These were followed in the 1950's by the well-known Physical Science Study Committee (PSSC) series of films, parts of which survive today in the videodisc series *Physics Cinema Classics* (Fuller & Lang, 1992). However, these films and many similar physics films produced in the following years had a major limitation—the control exercised by the classroom teacher or student is limited to turning the videotape on or off. Thus an important pedagogical consideration is severely limited during such passive viewing of these films, namely, the ability of the teacher to respond immediately and appropriately to the needs of the students (Zollman & Fuller, 1994).

Video-based laboratories have been reported positively in the science education literature (e.g., Beichner, 1996); in particular in physics education (Rodrigues et al., 2001). In these learning sessions, interactive video presentations are used to help students make observations, measurements and gather data about events. Such uses represent a quantitative use of these digital video clips. However, the program used in this study incorporates a qualitative use of digital video clips. Students do not make any measurements of objects in the video clips but are required to discuss and record detailed observations and use these as feedback as part of the POE sequences. The emphasis is on the articulation of rich, detailed, qualitative responses (both verbal and written), so important to learning in a social constructivist environment.

4.2.7 The digital video clips used in the program

Criteria for selection of clips: A major stage in the software development was finding appropriate video clips for the program. The video demonstrations needed to contain interesting and relevant material and where appropriate, surprising outcomes suitable for inclusion in POE tasks. The outcomes of demonstrations needed to be clearly visible and preferably rely on students' direct observation skills rather than second-hand observations using measurement instruments (White & Gunstone, 1992). The demonstrations needed to be suitably challenging for students in an introductory physics course but not too challenging to avoid students guessing and encourage personal reasoning. A balance between vertical motion, half-flight and full-flight projectile motions was required as well as a balance between active and passive (projectile) launches. Commercial sources of video clips needed copyright permission.

Final sources of clips: After extensive investigations and advice from the physics education community worldwide, three sources of video clips were found and where appropriate, permission was granted to use the clips in this study. Four tasks used clips digitised from commercial VHS tapes in physics education. Six tasks used clips from commercial CD ROM packages and a further six tasks used clips filmed by the author.

4.2.8 The influence of physics education research on the program

Alternative conception research on mechanics (e.g., Caramazza et al., 1981; Clement, 1982; Eckstein, 1997; Fischbein et al., 1989; Halloun & Hestenes, (1985a,b); McCloskey, (1983a,b); McDermott, 1984; Millar & Kragh, 1994; Twigger et al., 1994; Whitaker, 1983) informed the selection and creation of the video clips as well as the sequencing of the 16 POE tasks (refer to table 4.1). Common alternative conceptions emerging from this literature also informed the design of the multiple-choice options (or distractors) offered in the prediction stage of the POE tasks. Most video clips depicted scenarios designed to elicit different variations of pre-Newtonian alternative conceptions. Where possible, abstract situations discussed in the literature were adapted to an everyday, real world context for the video clips used in the program. This had the effect of creating highly rich contexts for the students, in line with constructivist strategies (Duit & Confrey, 1996; Jonassen & Reeves, 1996). For example, the pendulums discussed in Caramazza et al. (1981) and McDermott (1984) were adapted to a child on a swing (task 8). (NB. This does not imply that a child's swing is a perfect pendulum. However, for the purposes of eliciting alternative conceptions, this transfer of context was appropriate.) The famous scenario of a running person dropping a ball as discussed in McCloskey (1983) was adapted to the video clip of a walking child trying to drop a small ball into a cup on the ground (tasks 10 and 11). The canon ball discussed by McDermott (1984) was adapted to a soccer ball kicked into the air by a boy (task 7). Speed variations (tasks 4 and 5) and mass variations (tasks 5 and 6) as discussed by Millar and Kragh (1994) were incorporated into some of the tasks to help elicit naïve impetus views.

Some of the POE tasks used in the program have a rich history and have been considered by many scientists over the centuries. For example, task 12 (The Sailing Boat) involves the famous scenario of a ball released from the mast of a moving sailing boat. Students needed to predict where the ball would land: behind, below or in front of the mast. Galileo Galilei discussed this problem in detail in his *Dialogue Concerning Two Chief World Systems* published in 1632 (refer to section 3.2.3). There were six other POE tasks (refer to table 4.2) that could be linked to Galileo's famous 'thought experiments', some of which also appeared in his *Dialogues Concerning Two New Sciences* published in 1638.

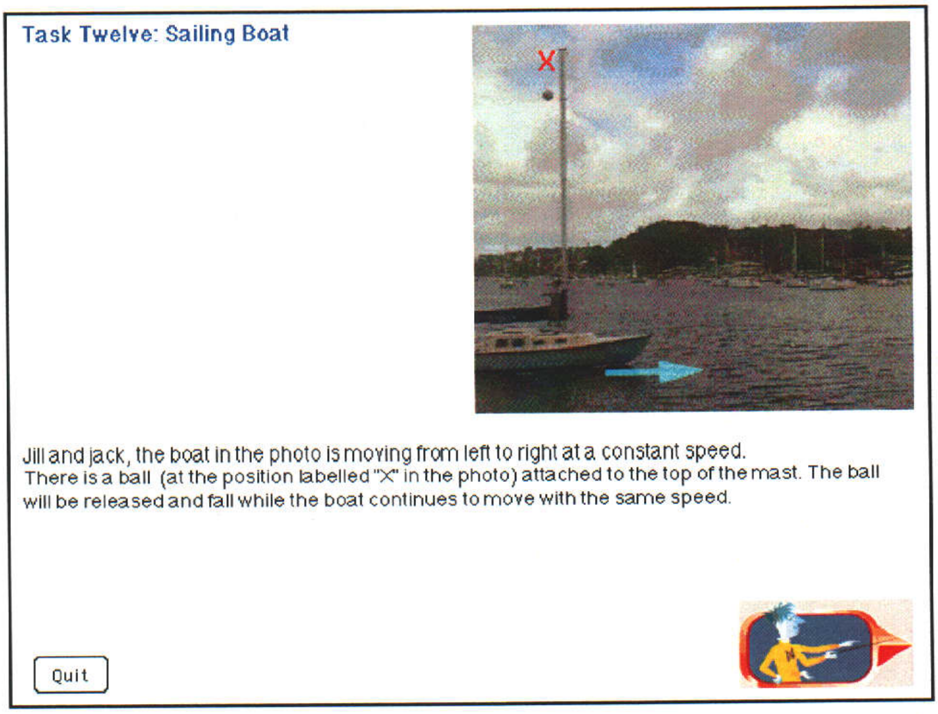
Table 4.2

Links between POE tasks used in the program and Galileo's 'thought experiments'

POE Task No. and Name	Context in Program	Context used by Galileo	*Dialogue Concerning...* (reference)
2. Rising Ball.	Small child throwing a ball vertically upwards	An object is launched upwards.	*Two New Sciences* (see Galilei, 1991, p. 165)
3. Ball Throw.	A person throwing a ball horizontally (from approx. 1m off the ground)	A person throwing a stone horizontally.	*Two Chief World Systems* (see Galilei, 1967, p. 151)
10 & 11. Ball & Cup	A walking person carrying and releasing a ball directly above a cup placed on the ground	A person riding on a galloping horse releases a ball.	*Two Chief World Systems* (see Galilei, 1967, p. 156)
12. Sailing Boat	A ball attached to the top of the mast of a sailing boat is released	A stone attached to the top of the mast of a sailing boat is released	*Two Chief World Systems* (see Galilei, 1967, p. 141)
13. Two Balls Falling	A ball is launched horizontally from a height at the same time as a second ball is released vertically (from the same height)	A cannon ball is launched horizontally from a height at the same time as a second cannon ball is released vertically.	*Two Chief World Systems* (see Galilei, 1967, p. 155)
14. Cart & Ball I	A ball is launched vertically upwards from a cart travelling horizontally	A cavalryman riding on a galloping horse throws a javelin vertically into the air	*Two Chief World Systems* (see Galilei, 1967, p. 157)

4.2.9 Screen sequence for each POE task

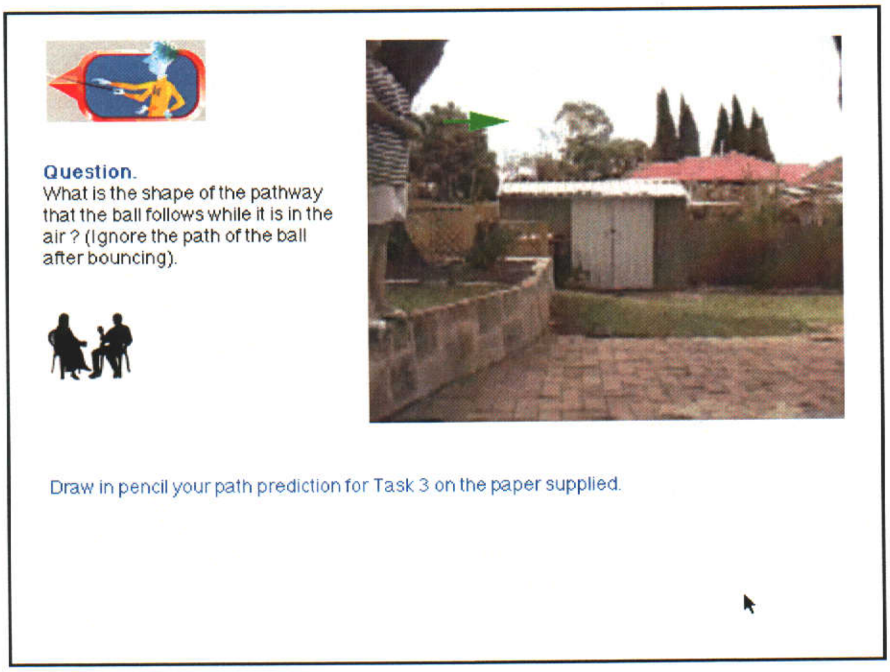
The first screen of each task includes a photo and a written description of the scenario to be considered (refer to Figure 4.1). The photo present on each initial screen was captured from the first frame of the relevant video clip for each task. In complex situations (e.g., task 12—The Sailing Boat), a brief video preview is offered (without showing the outcome of the demonstration) to help avoid ambiguities. The second screen of each task (or the third in the case of tasks with a video preview), displays the same photo and a question asking the student to predict an outcome. Six of the tasks (tasks 3 to 8) require students to draw their predictions on a prepared worksheet (see Figure 4.2 and also refer to Appendix C for sample worksheets). The other ten tasks



Task Twelve: Sailing Boat

Jill and jack, the boat in the photo is moving from left to right at a constant speed.
There is a ball (at the position labelled "X" in the photo) attached to the top of the mast. The ball will be released and fall while the boat continues to move with the same speed.

Figure 4.1. Screen shot of the opening screen for task 12 (final program)

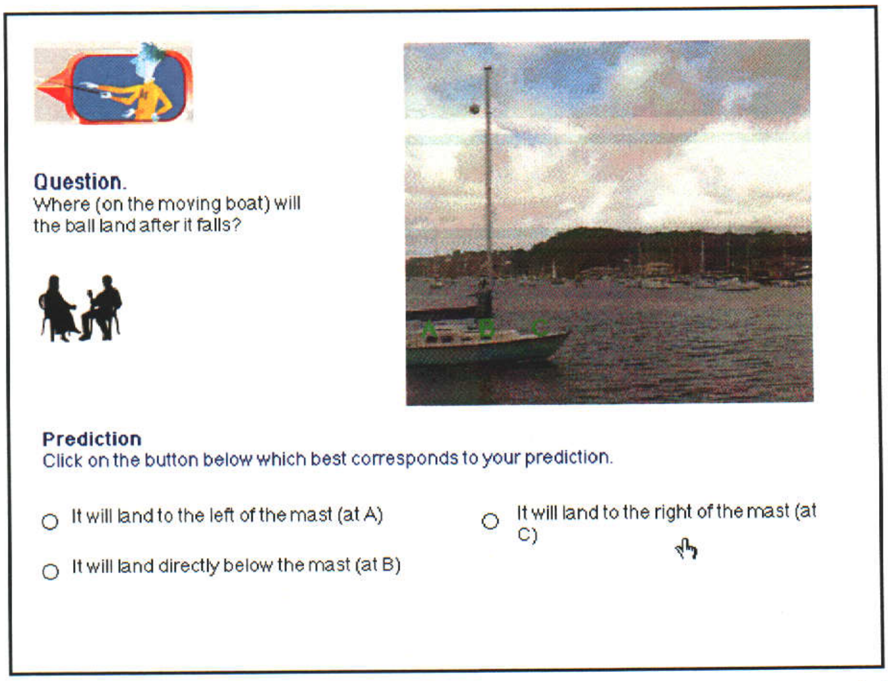


Question.
What is the shape of the pathway that the ball follows while it is in the air ? (Ignore the path of the ball after bouncing).

Draw in pencil your path prediction for Task 3 on the paper supplied.

Figure 4.2. Screen shot of the prediction screen for sample drawing task (task 3) taken from final program

require students to make their prediction by choosing from a selection of up to four multiple-choice options (see Figure 4.3). The options available to students here are based on known alternative conceptions from research in mechanics (refer to section 4.2.8), in the tradition of other multiple-choice diagnostic tests reported in the literature



Question.
Where (on the moving boat) will the ball land after it falls?

Prediction
Click on the button below which best corresponds to your prediction.

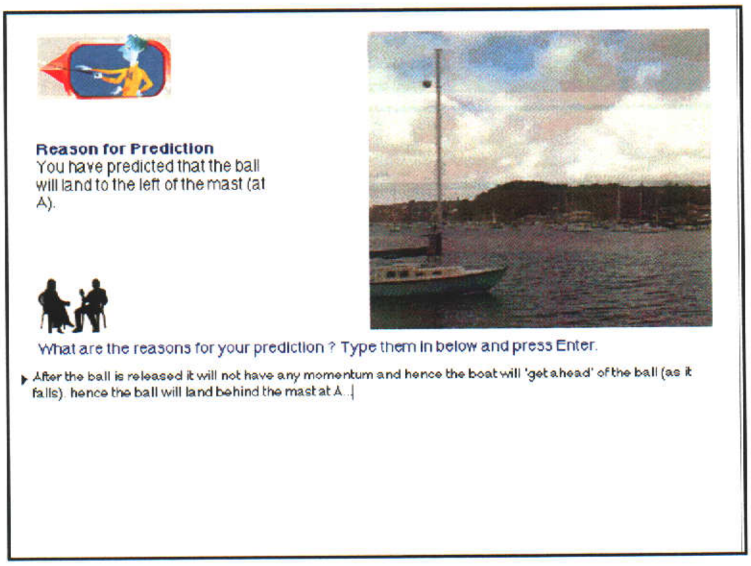
○ It will land to the left of the mast (at A)

○ It will land directly below the mast (at B)

○ It will land to the right of the mast (at C)

Figure 4.3. Screen shot of the prediction screen for sample non-drawing task (task 12) taken from final program

(e.g., Halloun & Hestenes, 1985a). Some of the tasks give the students a further option to record their own predicted outcome if they disagree with the options given. The next screen asks the students to give a reason for their prediction. A copy of their earlier written prediction also appears on this screen to facilitate reflection (refer to



Reason for Prediction
You have predicted that the ball will land to the left of the mast (at A).

What are the reasons for your prediction ? Type them in below and press Enter.

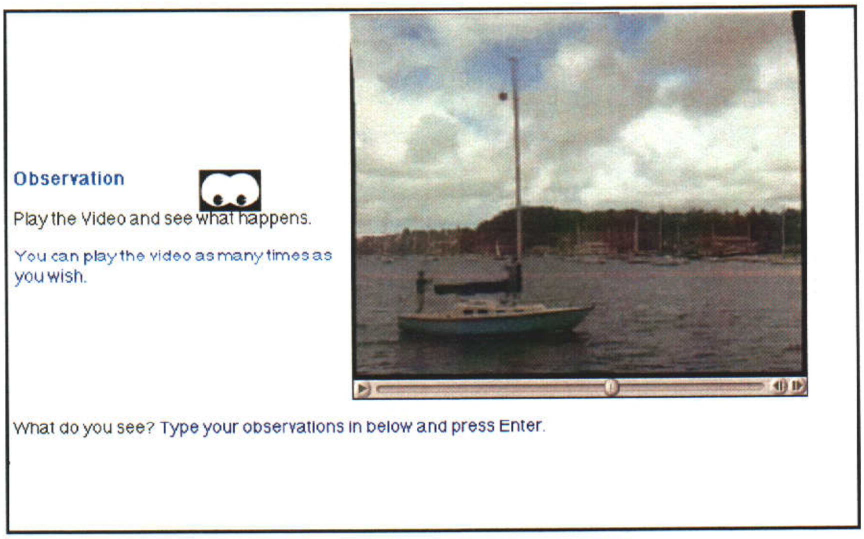
After the ball is released it will not have any momentum and hence the boat will 'get ahead' of the ball (as it falls). hence the ball will land behind the mast at A..

Figure 4.4. Screen shot of the reasoning screen for task 12 taken from final program

Figure 4.4). This strategy allows the students to articulate the reasoning behind their initial multiple-choice selection. This reasoning stage can be challenging but is an important stage as many students make a correct prediction but describe incorrect reasons (White & Gunstone, 1992). Students write their responses (in full sentence form) in a text input box shown on the screen. This is in accordance with Gunstone's (1995) recommendation that students write their predictions, reasons and observations to increase their level of commitment to their beliefs. All text input from users is recorded as a text file on the hard drives.

The software does not allow students to proceed to the observation (of the video demonstration) stage unless they have fully committed themselves to their prediction and reasons. If they want to go backwards and forwards and edit their prediction or reasons, they can do this, but not after proceeding to the observation stage. This ability of the multimedia program to structure these capabilities is crucial to the level of learner control and the overall effectiveness of the POE strategy in the small group, computer environment.

The next screen allows the students to observe the video of the event (refer to Figure 4.5). After approximately 10 seconds, another text input box shows on the screen (underneath the video clip) to allow students to describe and record their observations in detail. Students can replay and manipulate the digital video clip (using the QuickTime buttons and slider below the video clip) as many times as they wish before proceeding to the next screen.



Observation

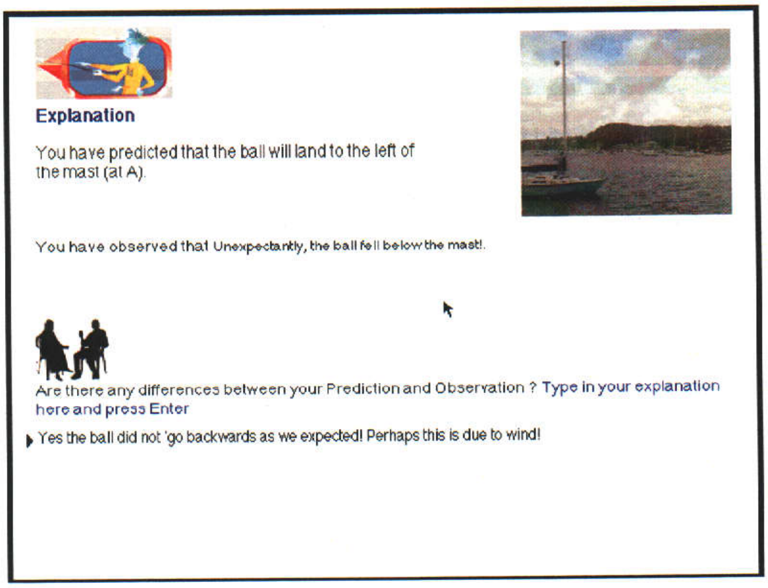
Play the Video and see what happens.

You can play the video as many times as you wish.

What do you see? Type your observations in below and press Enter.

Figure 4.5. Screen shot of the observation screen for task 12 taken from final program

The explanation phase is the focus of the final screen for each task (refer to Figure 4.6). This is perhaps the most difficult stage for students as they have to describe in writing any differences between their prediction and observation. A copy of their earlier prediction and observation is displayed on this screen to facilitate reflection.



Explanation

You have predicted that the ball will land to the left of the mast (at A).

You have observed that Unexpectantly, the ball fell below the mast!.

Are there any differences between your Prediction and Observation ? Type in your explanation here and press Enter

▶ Yes the ball did not 'go backwards as we expected! Perhaps this is due to wind!

Figure 4.6. Screen shot of the explanation screen for task 12 taken from final program

4.2.10 Summary

Science education literature informed both the selection and creation of the digital video clips for the computer-mediated POE tasks used in this study. Some of the physics scenarios have been considered for centuries and indeed several were considered by Galileo in his famous *Dialogues*. More particularly, alternative conceptions research informed the multiple choice options offered in the (non-drawing) POE tasks. The program is designed as a collaborative probe of understanding and aims to facilitate peer learning in a social constructivist environment.

4.3 The program as a new development in the use of the predict–observe–explain strategy in science education

The development of a multimedia computer program that uses digital video to present real life demonstrations within a POE framework has not been reported in the science education or education technology literature. Indeed, the collaborative use of such a program as a diagnostic instrument to probe understanding has not been reported.

The use of POE tasks within a computer environment has been reported sparingly in the literature. However, these reports usually discuss computer-mediated POE tasks that make use of abstract simulations (or do not follow the full POE procedure). For example, Tao and Gunstone (1999a) used computer supported POE tasks to investigate the process of conceptual change as well as the nature of the collaboration occurring at the keyboard. The students' responses were written on paper as students predicted what would happen if certain changes were made in the force and motion microworld. Demonstrations within the POE tasks were presented as abstract computer simulations (refer to section 2.2.4). Goldberg and Bendall (1996) reported on a program used for facilitating learning in geometrical optics. In this program, students were presented with a situation where they made a prediction about certain optics problems. They then observed what happened on the computer simulation, evaluated their observation and compared it with their prediction. Once again, animated simulations (as distinct from video footage of real-life events) were used as the stimuli in these tasks.

Hence the program used in this study represents a new development in the use of the POE strategy in science education. Professor Richard Gunstone acknowledged this new development in his written review of the program after the completion of the final version:

> I first viewed this CD approximately 12 months ago, and did so thoroughly. My essential motivation for being thorough was that, as one who claims to be partly responsible for the development of the POE teaching strategy, I have predictable (but regrettable) feelings of possessiveness about "my" creation. I have recently looked again at the CD before writing this statement.
>
> The CD and the associated approaches to its use in classrooms mark a significant and valuable development in the use of POEs. There are two essential aspects of this significance.
>
> 1) The sequencing of a series of stimuli (video clips) in a carefully planned and well justified series of tasks is a new use of POEs, and a highly appropriate one. In one sense what Matthew has done with this CD is to take a valuable teaching strategy that has become quite widely used in individual classroom episodes and use the strategy in more systematic and strategic ways.
>
> 2) While others in the past have used film/video clips already available as stimuli for POEs, this CD is an important further step in that there is so much by way of video that has been specifically created for the CD. This creation has been very well done—the specific ways that the individual video clips are intended to contribute to student learning are clear (an obvious measure of the extent to which there is clear and substantive justification for the nature of the specific clips).
>
> (Review of multimedia program used in this study by Prof. Richard Gunstone, Acting Dean and Professor of Science and Technology Education, Faculty of Education, Monash University, Victoria, Australia.)

4.4 Field testing the program

A prototype of the program was trialed by two separate groups during October 1998. The first trial was with a physics class at the University of Sydney International

Preparation Program. The use of students in this trial followed Willis's (2000) suggestion to include the perspective of the user in the design process of constructivist educational software (refer to section 4.1). Students were observed by the author, their written responses from each POE task were collected from the hard drives, verbal interactions were recorded on audiotape and they completed a feedback questionnaire after their session. The questions were designed to elicit the students' perceptions of technical issues relating to the user interface, navigation and ease of use of the program as well as pedagogical issues relating mainly to their collaborations at the computer. The second trial was completed by a professor of science education and two senior academics from the physics department at Curtin University, Perth. At this stage, the prototype of the program only contained ten tasks that could be selected by the students in any order. It did not contain any of the film clips made by the researcher and also contained one task that eventually was deleted from the final version of the program. The astronaut task was missing from this original version and there were no tasks requiring students to draw responses. In the light of these two trials, significant alterations were made to the program before a trial of the final version of the program proceeded in January 1999.

4.4.1 Trial of prototype with student group

Students' written responses to the tasks revealed many pre-Newtonian conceptions, especially in the reasoning stage of the POE task (and often after a correct prediction). For example, in task 6 (Car Launch) two students gave the following reason for their predicted pathway for a car driven off a cliff: "It is because the momentum of the car will push the car further forwards". The term *momentum* is often used by students in the context of imparting or impressing *impetus* on an object (refer to section 3.3.3). Two other students believed that the ball in task 1 (Falling Ball) would fall at constant speed, a common alternative conception (McDermott, 1984).

Meaningful conversations were observed and data from the audiotapes were in agreement with these observations. Feedback from the student questionnaires indicated that the students also perceived meaningful conversations taking place during their engagement with the program. For example, one of the questions on the questionnaire asked the students if they had any conflicts and how they negotiated agreements in their responses. One student responded: "Yes [we did have conflicts] sometimes. [We negotiated agreement by] explaining to each other the reason and making our point of view clear." His partner agreed with this claim. In response to another question addressing the level of awareness of his partner's ideas, he mentioned: "Yes I did [become aware of my partner's ideas]. We discussed our ideas and got a final result together...."

Students used the questionnaires to make valuable suggestions for improvements in the program. A common complaint was the absence of a *back* button to allow students to return to previous screens and edit responses. (Of course this would not be allowed after viewing the video demonstration!) The ability to edit written responses (inside the text input boxes) was another complaint. Students generally found the demonstrations interesting with an element of surprise in many of the tasks.

4.4.2 Trial of prototype with academics

The three academics from Curtin University used a special technique where the computer that they were using was linked to the video recorder to provide a visual record of the screen display superimposed on the videorecording of them engaged in the computer tasks. (i.e., Their faces and conversations were filmed simultaneously with the contents of the computer screen). This technique is discussed in Yeo et al. (1998) and Russell et al. (1999). The academics made many helpful suggestions about screen design and also the language used in the tasks. They mentioned the need for a *back* button to allow students to edit predictions and reasons (before viewing the video). They advised on a small set of instructions for first time users to clearly explain the QuickTime toolbars and to let users know that they can assume an equal time interval between each frame on any video clip (a key assumption to be made when making inferences in tasks such as the Falling Ball and Rising Ball). They perceived a problem with the multiple-choice options for tasks involving the prediction and observation of possible projectile pathways (e.g., the car launched off a cliff.) The prototype program only had four (text) distractors for such tasks. For example, the Car Launch task had the following written options: *semi-circle*, *straight line*, *parabola* or *other*. It was pointed out that many students may not know an accurate definition of a parabola or semi-circle. As a consequence of this feedback, it was decided that a multiple-choice format was not suitable for tasks involving pathway predictions. There were too many possible outcomes to be covered by multiple-choice options and it was difficult to avoid ambiguous distractors. Indeed, more detailed data could be gained from student drawings of these pathways (White & Gunstone, 1992). Hence, tasks 3 to 8 were designated 'drawing tasks' where students' predictions and observations would not be recorded on the computer but instead would be recorded on paper drawings.

Their main criticism made by the Curtin academics, however, was that the correct science views for each task were not given at all. This was also mentioned in the student trials. Consequently, a separate instructor's version of the final program was made which included answers to each task. The reviewers generally agreed that the prototype was motivating, contained many everyday contexts and the underlying physics principles were appropriate and accurately presented.

4.4.3 Changes in the program resulting from these trials

Apart from the creation of a separate instructor's edition of the program and designating some tasks as 'drawing tasks', both of these trials lead to other major changes before the final version of the program was completed. Six extra tasks were added to further align the program with alternative conception research in mechanics. For example, the ball and cup task was re-named the 'heavy ball and cup' task. An additional 'light ball and cup' task was then created to help identify students who held naive impetus preconceptions relating to mass variations in objects (Millar & Kragh, 1994). In this additional task, a small child walking towards a cup was filmed dropping a light ping-pong ball (in contrast to the heavy ball in the preceding task).

The random sequence in which students did the 16 tasks was also changed. Guidelines for the development of constructivist software generally encourage a low structure, non-linear sequence and a high degree of student access to material; providing students with many navigational opportunities (Kennedy & McNaught, 1997). However, this was not possible for this particular program. Data from the student trial group indicated that students' observation of certain video clips could easily influence their responses in subsequent tasks. (This defeated the purpose of the program as a probe of students' personal pre-instructional science views.) Hence the tasks where students had to draw their predicted and observed pathway needed to be in the first part of the program. It was also decided that for the purpose of the research study, the POE tasks would be attempted in a linear order (i.e., starting at task 1 and finishing at task 16).

The trials resulted in many other minor but important changes in the program. The format of the text file (which recorded student responses) was made more user-friendly. A compulsory tutorial (at the start of the program) was developed to help students gain familiarity with the software and particularly with the QuickTime toolbar (refer to Appendix D for screen shots of this tutorial). The ability to go back to previous screens and edit responses (a strong criticism of the beta version) was also incorporated into the final version of the program—although it was still not possible to change predictions and reasons after viewing the video clips. Screen design issues also were addressed including changing the background colour back to white for ease of reading, and the addition of arrows to point out important parts of graphics. Small icons (in conjunction with text statements and questions) acting as 'process prompts' (Lin et al., 1999) were placed on appropriate screens. The icon shown in Figure 4.7 was used to prompt students to discuss and reflect on their responses. For example,

Figure 4.7 A 'process prompt' used in the final version of the program to initiate student discussion and reflection

Figure 4.8 A 'process prompt' used in the final version of the program to initiate student observation

after the students made a prediction, they were reminded of this decision on the following screen before being asked to reflect on, discuss and record the reasons for their prediction (refer also to Figures 4.2 to 4.6) The icon in Figure 4.8 was used to prompt students to closely observe the digital video scenarios (refer also to Figure 4.5).

4.4.4 Field test of final version

The final version of the program was successfully trialed and fine-tuned with another small group of students from the Sydney University International Preparation Program during January, 1999. In this trial of the final version of the program, meaningful conversations were again observed and interesting written responses again revealed alternative conceptions. The student drawings (made during the new 'drawing tasks') in this trial revealed some classic pre-Newtonian beliefs (e.g., refer to Figures 4.9 and 4.10). Brief interviews replaced written questionnaires in this final trial and there was generally a positive feedback regarding this expanded final version of the program. Small ambiguities and technical problems from the earlier prototype had been solved and the only major change made after this final trial was the format of the paper worksheet accompanying the program. Students in this trial made their drawings (for tasks 3 to 8) too small or too large or did not distinguish between their prediction and observation. A new worksheet was created whereby students had to draw their prediction as a continuous line and their observation as a dotted line. The scale of their drawings was controlled by printing an appropriately scaled background picture of the

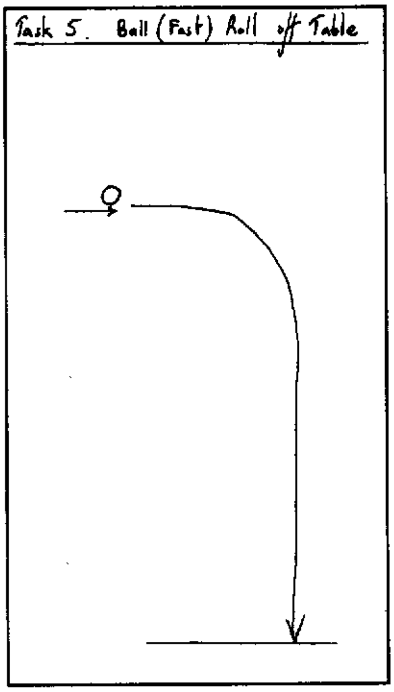


Figure 4.9. A classic impetus prediction for a fast ball rolling off a table (task 5). Drawing taken from a sample student in the trial of the final version of the program.

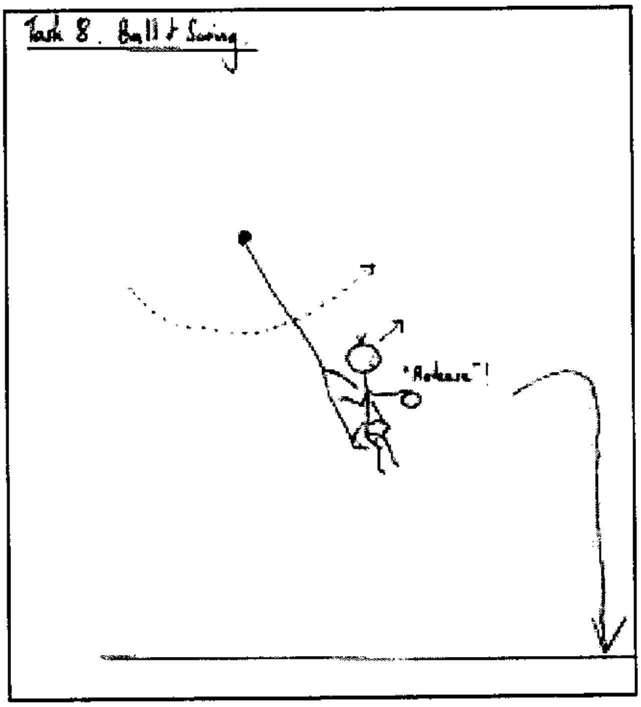


Figure 4.10. An incorrect prediction for a ball passively released by a person on a swing (task 8). Drawing taken from a sample student in the trial of the final version of the program.

context (e.g., a car and a cliff) into the background of the paper worksheet (e.g., refer to Figures 7.15 to 7.17 and also refer to Appendix C).

4.5 Conclusion

The program used in this study promotes the collaborative use of 16 multimedia-supported POE tasks as an instrument to elicit students' views and like any probe of understanding, also provides students with an opportunity for learning. Such use of the POE strategy has not been reported in the literature. Indeed, the program's use of digital video clips of everyday scenarios, embedded in the computer-mediated POE tasks, represents a new development in the use of the POE strategy in science education.

Science education literature, particularly research relating to constructivism, informed the design of the program at all stages of development. There was an extensive formative evaluation of the program. A prototype was used by a physics class and valuable 'user feedback' was received and informed further development of the program. This process of involving the users' perspective in the design process follows general software design guidelines based on constructivist theory (Willis, 2000). The prototype was also extensively trailed by three senior academics from Curtin University. Many important changes were made to the software as a result of these trials; for example, six tasks were changed to accept 'drawing' responses and some new tasks were added. Discussions of the design and development process made in this chapter will facilitate a greater understanding and further insights into the findings and conclusions sections of this study.

CHAPTER 5
METHODOLOGY

5.0 Overview of chapter

This chapter makes a case for the use of an interpretive, dual case study methodology to investigate the classroom use of computer-mediated POE tasks designed to elicit and promote meaningful discussion of students' science views. Data collection and analysis procedures are outlined before discussing the study's rigour and ethical issues. Finally, insights into the class environments of both cases are given to facilitate the reader's understanding and interpretation of findings presented in subsequent chapters.

5.1 Background

Traditionally, educational research has been conducted using controlled empirical studies based on a positivist belief system. However, over the past two decades, there has been a growing disenchantment with the application of this traditional research paradigm of the physical sciences to the study of human behaviour and educational phenomena (e.g., Lincoln & Guba, 1985). Positivist educational research attempts to uncover laws about humans which apply at all times and places but unfortunately educational settings become artificial when variables start being controlled, affecting the relevance, replicability and generalisability of studies. Given the complexity of human beings and their behaviour, these empirical studies become problematic: "Discrete variables and their relationships do not seem to be sufficient to deal with the complex interactions and patterns of human behaviour" (Neuman, 1989, p. 41).

Under the constructivist paradigm, a relativist ontological position is taken whereby reality can have multiple interpretations (refer to section 2.1): "Truth is a matter of consensus among informed and sophisticated constructors, not correspondence with an objective reality" (Guba & Lincoln, 1989, p. 44). This interpretive paradigm encourages researchers to look at context as a dynamic whole, including individual and sociohistorical backgrounds (Duffy & Cunningham, 1996). This is in sharp contrast to the traditional objectivist perspective that views context as separate from the learner and able to be manipulated.

The case for more qualitative, interpretive research in science education was made in the early 1980s by Easley (1982) and Rist (1982). Similarly, educational technology theorists such as Neuman (1989), Salomon et al. (1991) and Selwyn (1997) have called for an approach to educational technology research that takes the focus away from the technology towards the types of activities that innovative technologies can afford. They advocated more naturalistic studies that could provide appropriate data about relevant social and cognitive processes in order to explore the affordances of innovative technologies (refer to section 2.3.2). Despite these recommendations, Weller (1996) pointed out that many studies investigating technology use in science education have continued to be media comparison studies adopting quantitative methods. A lack of insightful qualitative data in these studies has been noticeable: "In their endeavours to control all other variables, [they]...may have missed some of the richness of the interconnected network of variables involved in the human experience of learning and doing science" (Weller, 1996, p. 480).

Important variables in this project were indeed too intricate and numerous to isolate and measure in a positivist, comparative study. Instead, a constructivist belief system was chosen to inform the interpretive methodology adopted in this study. Under this paradigm, this study does not attempt to provide universal laws or generalizations. Conclusions and findings are designed to be read and interpreted based on the reader's own background knowledge and contexts.

5.2 Introduction to study

The study adopts an interpretive methodology (Guba & Lincoln, 1989) to investigate a Year 11 physics class and a Year 10 science class using 16 computer-mediated POE tasks incorporating digital video clips of real life events. Students used the program in collaborative pairs at the beginning of their study of motion for the purpose of eliciting and promoting discussion of their pre-instructional ideas. The study does not attempt to address conceptual change issues but rather focuses on the use of the program to promote discussion, reflection and probing of students' science views. Some quantitative data supplemented the rich qualitative data collected in the study.

5.2.1 Interpretive case study method

A dual case study (Merriam, 1988) design was adopted in this research to gain an insightful, qualitative interpretation and description of the implementation of an innovative technology within two science classes. This arrangement was not made to set up a comparative case study but to provide a diversity of context-bound data. This approach was suitable because the phenomenon (various aspects of student and teacher use of 16 computer-mediated POE tasks) was complex and the aim was to understand the context more deeply; to create a 'true picture' of what was happening in this setting: "By concentrating on a single phenomenon...this [case study] approach aims to uncover the interaction of significant factors characteristic of the phenomenon" (p. 10).

5.2.2 Major use of qualitative data

Bogdan and Biklen (1998, p. 4) describe five characteristics of qualitative research. Firstly, the study is naturalistic; the actual settings are the direct source of data and human behaviour is significantly influenced by these settings. Secondly, the study contains descriptive data that takes the form of words or pictures rather than numbers and measurements. Thirdly, the study is concerned with process rather than just outcomes. Fourthly, findings are made inductively—no data are held as evidence to prove or disprove hypotheses—or alternatively, theory is grounded in the data. Finally, meaning is concerned with participant perspectives and procedures are set up to enable the researcher to consider experiences from the informant's perspective. This study satisfies all these conditions. All data emerged from the settings of two science classes using a computer program. Data were mainly descriptive and concerned with the process of learning (e.g., the focus on collaborative learning processes in chapter 6). Findings were made in the form of general assertions that emerged from the data while student and teacher beliefs and perceptions were a major contribution to these data.

5.2.3 Minor use of quantitative data

Advocates of interpretive, naturalistic studies have acknowledged the possibility of combining both qualitative and quantitative methods. For example, Patton (1987) endorsed quantitative data as a supplement to qualitative data whilst Lincoln and Guba (1985) mention the unique opportunity to combine both data types:

> ...the naturalistic and conventional paradigms are so often—mistakenly—equated with the qualitative and quantitative paradigms, respectively. Indeed, there are many opportunities for the naturalistic investigator to utilize quantitative data—probably more than are appreciated. (p. 198)

Accordingly, some quantitative data were collected in this study to supplement the predominantly qualitative data. This mainly occurred through the use of Likert-style questionnaires, especially during the investigation of class backgrounds.

5.2.4 Summary

A constructivist belief system informed the dual case study design of this investigation. Some quantitative data were collected to supplement the rich, detailed qualitative data in the study.

5.3 Participants and setting

Two classes from two separate, independent, single-sex secondary schools in Sydney participated in this study. The first was a Year 11 physics class following the NSW Higher School Certificate (HSC) physics course. The class consisted of 19 girls and their female teacher. The second was a Year 10 advanced level science class from a different school and consisted of 27 boys and their male teacher. (N.B. As mentioned previously, gender issues were not a focus of this study.) The classes were chosen because of the interest expressed by the teachers associated with them. Both teachers had over 15 years experience teaching science, were highly respected by their peers and were considered to be innovative and skilled professionals. They were both familiar and comfortable with constructivist learning theory and valued student discussion and reflection on their science conceptions in collaborative settings (refer to section 5.9 for a more detailed background on participants and their class environments). For example, the following extract comes from the researcher's field notes and was made after an initial phone conversation with Judy:

> My initial telephone conversation with Judy indeed gave me the impression of someone who was strongly committed to her teaching profession and very keen to implement new ideas. I vividly recall her response during this initial phone call when I informed her of the theoretical underpinnings of my research: namely constructivism. She responded: "Yes, I'm heavily into that!" Her obvious interest in my research (even at this initial stage) was most encouraging and reflected her strong interest and motivation in science education.

Prior to the commencement of the study, all students had only studied basic force and motion concepts (e.g., distance, speed, pulls and pushes) in their previous junior high school science units. Background data (refer to section 5.9) indicated that most students were competent and confident computer users, were familiar with the predict–observe–explain strategy and were familiar with collaborative learning strategies.

5.4 Data collection and description of lessons

The following data sources were used in the study: participant observation, field notes, collected documents, audio and video recordings, semi-structured interviews and questionnaires. The main foci of the data collection were two computer sessions when the students and their teacher engaged with the POE computer tasks. Formal interviews were held a few days after these sessions. Important insights into each class environment also were gained through class visits both before and after these computer sessions. Altogether, approximately three weeks were spent with each class (refer to Table 5.1 for schedule) and these visits coincided with the start of the students' study of motion. Contact with the teacher of each class lasted approximately ten weeks, including general information sessions, preliminary planning, phone calls, organizing permission notes and informal interviews. Each class in this dual case study was considered 'one case at a time' as recommended by Bogdan and Biklen (1998, p. 63). The visits to the girls' class occurred during term one, 1999 and the visit to the boys' class occurred during term two, 1999.

5.4.1 Pre-computer sessions

As well as providing an insight into the class environments, these early sessions served a number of other purposes. The students and the teachers completed two background questionnaires during these sessions. The first was devised for the purpose of becoming familiar with the students' background and previous experience using computers. The second, the *Constructivist Learning Environment Survey* or CLES (Taylor, Fraser, & Fisher, 1997), was used to gain an insight into the students' and teacher's perceptions of their normal science classroom learning environment. These sessions also helped students become comfortable with the researcher in the room as a participant observer and helped to establish a sense of trust and rapport between the students, the teacher and the researcher. Hence, these sessions helped to reduce the 'Heisenberg effect'—or 'observer effect'—in this study. (According to this theory, all observation disturbs what is being observed. In the case of a predominantly qualitative study like this one, the researcher may change the behaviour of the people in the study.) There were frequent informal interviews with the teachers and documents were collected during these early class visits. For example, the Year 11 students did some teacher-directed (classroom-based) POE tasks using ticker tape during a lesson leading up to the computer sessions. Their responses during these tasks were collected. These activities also were used to make sure students were totally familiar with the POE strategy. Finally the sessions were used as an introduction to the structure and purpose of the computer-mediated POE tasks and to demonstrate the full capabilities of the QuickTime video facilities (step-frame, slow motion etc.) to be used in the subsequent computer-based sessions.

5.4.2 Computer sessions

The students worked in pairs with the program for two lessons and during this time they completed the 16 POE computer tasks. (NB. A rationale for the use of student pairs in this study is given in section 5.7.3) The Year 11 class worked in the school library on seven desktops and three laptop computers. The Year 10 class worked in the school computer laboratory on desktop machines. Audio recording devices were placed in front of every student dyad in the class to record their conversations during these sessions. Four video cameras were used to record events. Three cameras focused on three separate pairs of students to record off-computer interactions and activities as well as gaze directions, body language, postures, facial expressions, pointing and other non-verbal gestures. (These groups were chosen upon recommendation from the class teacher.) The cameras did not focus on the computer screens but rather were placed beside the computers, facing the students. The other camera focused on the whole class and monitored the teacher movement, inter-group dynamics and also served as a (long-range) recording of groups not closely monitored by the other three cameras. This video footage carried a wealth of visual information that helped to reconstruct the social dynamics of the classroom and add meaning to audio recordings. All video and audio equipment was positioned to minimize intrusiveness on the students. For example, the audio tape recorders could actually fit under the desktop screens with just the front sections (containing the microphones) revealed. Small dictaphones were used with students using the laptops.

Students typed responses were automatically stored in a text file on the computer as a source of data for the study (refer to Appendix B) and their pencil and paper drawings were also used as a data source (refer to Appendix C). The researcher recorded field notes during these sessions in the role of participant observer. These notes were updated and completed after each session. Immediately after the second computer session, all students and their teacher completed individual questionnaires about their experiences during the computer lessons. The student questionnaire, *My Experience Using the POE Computer Tasks,* comprised 60 Likert-type items that were designed by the researcher to help probe student perceptions and beliefs relating to the research questions (refer to Appendix E). A similar questionnaire, *Reflections on the POE Computer Tasks,* was designed for the teachers and comprised 74 Likert-type items (refer to Appendix F).

5.4.3 Formal interview sessions

Some sample students and their teachers were formally interviewed around the time of their next scheduled lesson. Students were selected for these semi-structured interviews (Burns, 1998) by means of purposeful sampling (Bogdan & Biklen, 1998) based on their questionnaire responses, analysis of field notes and teacher recommendations. They were interviewed in pairs, using the same groups that worked together during the computer sessions. The researcher used printouts of key photos from each task to prompt responses from informants. This type of interview was used to allow students and the teacher flexibility in answering questions and to facilitate a more detailed insight into their perceptions. However, open-ended questions were used to guide the discussions and make use of the limited time available to interview the students (approximately 25 minutes per group). Verbatim transcripts of interviews were made and used in the data analysis.

Table 5.1

Outline of schedule for class visits (repeated in both schools)

Stage	*Research Interests*
Pre-computer session one	Introduction and explain purpose of research; Observation of class environment; Observation of teacher-lead POE tasks; Post session teacher interview (informal)
Pre-computer session two	Observation of class environment; Observation of teacher-lead POE tasks; Questionnaire: *Constructivist Learning Environment Survey* (completed individually) for students and teacher; Post sessions teacher interview (informal)
Pre-computer session three	Observation of class environment; Introduction of computer program to students e.g., use of video clips, program structure, purpose etc.; Questionnaire: *Attitude to Computers Survey* for students (completed individually); Post-session teacher interview (informal)
Computer session one	Recording of conversations on audio tape; Recording of non-verbal interactions on video tape; Recording of students' written responses (automatically stored by the program as text files on each computer); Participant observation; Post-session teacher interview (informal)
Computer session two	*As above* + Questionnaire: *My Experience Using the POE Computer Tasks* (completed individually) for students and teacher; Post-session teacher interview (informal)
Outside Class Time	Semi-structured student interviews (formal)—4 sample groups (same pairs as computer sessions); Semi-structured teacher interview (formal)
Post-computer session one	Further observation of class environment; Observation of any whole-class discussion of POE scenarios from computer sessions
Post-computer session two	Further observation of class environment; Observation of any whole-class discussion of POE scenarios from computer sessions

5.4.4 Post-computer sessions

Participant observation was the main data source during these (classroom-based) sessions. The aim of these post-computer sessions was to gain further insight into the class environments and observe any whole class-based discussions of the POE scenarios encountered by the students during the computer sessions.

5.4.5 Summary

An intense period of mainly qualitative data collection occurred during the computer sessions held with each class. Further data were collected during class visits both before and after these sessions.

5.5 Data analysis procedures

Data analysis proceeded both during and after the data collection (Merriam, 1988). Special arrangements for the analysis of collected student documents, questionnaires, audio and video tapes are outlined in this section. General assertions made in the study were grounded in the data.

5.5.1 Students' written responses and drawings

The students' written responses were retrieved from their computers as text files, collated and returned to the teacher for possible use in subsequent lessons. These documents, together with the students' paper and pencil drawings, were used as data mainly in the discussion of Research Question 2 (refer to chapter 7). For example, all (written and drawn) predictions, reasons, observations and explanations were scrutinized for alternative conceptions and categorised into various types of mainly pre-Newtonian beliefs (refer to table 7.2). Relevant student drawings were scanned and digitized. These responses also were used to identify some possible critical incidents as a focus for the audiotape analysis.

5.5.2 Audio tape analysis

Audiotape data from all groups were analysed from a social constructivist perspective (refer to section 2.2.2). Tapes were viewed and analysed with the students' written and drawn responses in full view. Critical incidents that were relevant to the research questions were identified and transcribed immediately, providing 'thick description' (Guba & Lincoln, 1981) of key events. If there was any relevant non-verbal behaviour to investigate, the video recording of the whole-class was viewed to facilitate further rich description of these incidents. Where possible, critical incidents also were checked with relevant data from field notes, interviews and questionnaires.

It must be noted that the recorded student conversations were intended primarily as a data source in the investigation of the students' learning conversations (in Research Question 1). The prime data sources used to investigate the students' actual science views (in Research Question 2) were the students' written responses and drawings. The audiotape recordings were not used as a source of data in this section of the study (chapter 7) for two main reasons. Firstly, the students' written responses and drawings provided a more than sufficient collection of alternative science views for discussion and analysis. These written responses and drawings often represented ideas exchanged during conversations anyway. Secondly, in the 'everyday' context of using this computer program as a diagnostic probe, audiotaped student conversations are not intended to be a source of data (i.e., outside the realms of this study). This would be too time-consuming and cumbersome for the teacher. (Indeed, as previously stated, it was intended that the program be a more efficient instrument than other diagnostic 'tools'.) Students' written responses and drawings were always considered the prime data source for the analysis of students' science views elicited by the computer program. Hence, to reflect these normal teaching constraints, the audiotaped student conversations were not used as a source of data for Research Question 2.

5.5.3 Video analysis

Close-up video footage of each of the three focus groups were analysed thoroughly for critical incidents. The video cameras' microphones had 'picked up' the conversations of each group and the video tapes were viewed in light of the students' written and drawn responses. Transcriptions of critical incidents contained sufficient narrative and commentary to describe relevant visual data such as off-computer activities, gestures, posture, gazing etc. Where possible, critical incidents were checked with relevant data from field notes, interviews and questionnaires.

5.5.4 Questionnaire analysis

Only two scales of the CLES were used as data in the study, providing relevant insights into the student and teacher perceptions of their normal class environment (refer to section 5.9). A reliability analysis was performed on both class sets of CLES data. Data from the questionnaire *My Attitude to Computers* also were used to provide insight into the students' attitude to technology.

The most important source of questionnaire data in this study came from student responses to the survey titled: *My Experience Using the POE Computer Tasks.* Relevant items from this questionnaire were grouped together and used as data in all three foci of the study.

5.5.5 Formation of assertions

Generalizations and claims were formed from the data in two strategic ways. Firstly, they were formed through direct interpretation of individual instances. Secondly, they were formed by an aggregation of instances (across both cases) until general themes emerged (Stake, 1995). These interpretations and themes were stated as general assertions that were grounded in the data and were reformulated and refined as the study proceeded (Merriam, 1988). These assertions provided a framework for discussion of findings in the study.

5.6 Rigour of study

The rigour of any study is important regardless of the theoretical framework. Traditional empirical research uses the qualities of validity, reliability and objectivity to describe the rigour of a study. However, Guba and Lincoln (1989) suggested that these criteria have their foundations rooted in a positivistic paradigm. They suggested the following alternative criteria for a rigorous, 'trustworthy' interpretive study: credibility, transferability, dependability and confirmability. The rigour of this study will be discussed using these attributes.

5.6.1 Credibility

The credibility criterion may be thought of as parallel to internal validity. Lincoln and Guba (1985) suggested five major techniques that enhance the credibility of findings and interpretations in a study of this nature. Prolonged engagement in the field, persistent observation, triangulation, peer debriefing, negative case analysis, referential adequacy and member checks. Although practical considerations interfered with some of these techniques, most of them were utilized in this study.

Prolonged engagement in the field and persistent observation. The research was relatively short-term for an interpretive, qualitative study for a few reasons. Firstly, the goals of the study focused on an intensive period of data collection as each class made use of the computer-mediated POE tasks. Secondly, the study had to fit into the busy schedule of each class, dictated by heavy syllabus demands. The Year 11 class in particular had considerable time constraints as they followed the demanding NSW senior physics syllabus. Hence, there was a limited time of access to each class and any further demands would have exploited the relationship with students, teachers and their school. Despite these constraints, the actual data collection was intense and incorporated persistent observation.

Triangulation. There were two forms of triangulation in this study that contributed to its credibility. Firstly, a variety of data sources was used to triangulate findings, including a mixture of qualitative and quantitative methods. For example, interviews, participant observation and collected documents were used in the study in combination with data from questionnaires. Secondly, the data depicted perspectives from students, teachers and the researcher and these were used to confirm assertions made in the study.

Peer debriefing. Peer debriefing was held throughout the data analysis. Regular discussions with academics from Curtin University, Perth and the University of

Technology, Sydney provided constant feedback on assertions and interpretations from the study. Preliminary findings were submitted and published as works in progress at various national and international conferences (see relevant publications in the preface to the thesis), resulting in two fully refereed journal articles prior to thesis submission. Peer reviews of these publications provided valuable and fresh insights into aspects of the study.

Negative case analysis, referential adequacy and member checks. Negative case analysis involves the refining of findings until all known cases are accounted for. This study followed this procedure through regular attempts to find data that refuted preliminary assertions and subsequent modification of these findings to cater for such data. Referential adequacy also was followed. Videotape and audio recordings were analysed after preliminary findings were established, to provide a "benchmark against which later data analyses and interpretations could be tested for adequacy" (Lincoln & Guba, 1985, p. 313). Member checks (or respondent validation) occurred to a degree with the two teachers but were not possible with students due to limited access after the official research period.

5.6.2 Transferability

Transferability is parallel to external validity or generalisability from positivistic studies. This criterion is fulfilled in this study mainly through the use of 'thick descriptions' of critical incidents that contribute to an understanding of the findings. These descriptions are layered enough to uncover the intentions of a given act, event, or process (Guba & Lincoln, 1981). They were used in this study to help emphasise the voices and actions of participants and the reader must interpret such findings for themselves.

5.6.3 Dependability

From a constructivist perspective, the traditional reliability criterion for a rigorous study is 'replaced by' *dependability* (Guba & Lincoln, 1989) or the stability of data over time. My findings do not claim to be universal and generalisable but present a report of what happened in two classes at a particular time with a particular teacher using an innovative technology. Any generalizations from this qualitative study are located in the relationship between the text and the reader. To help satisfy the dependability of a study, Lincoln and Guba (1985) and Merriam (1988) suggested the researcher make the process 'trackable' by leaving an *audit trail.* The processes followed and any interpretations made in this study have therefore been made explicit at all stages.

5.6.4 Confirmability

Traditional studies based on a positivistic paradigm seek to achieve objectivity by conducting an inquiry that is neutral, free from bias, value judgements or prejudice. Constraints like this cannot be applied to naturalistic research because the focus is on human beings and they vary in many ways. From a constructivist perspective, objectivity is replaced by *confirmability*, where the integrity of the findings are embedded in the data (Guba & Lincoln, 1989). For example, there is a need for assertions in interpretive research to be 'trackable' and consistent with the context from which they are derived. The audit trail mentioned in the previous section contributes to the fulfillment of this criterion.

5.6.5 Summary

The study uses the constructivist notions of credibility, transferability, dependability and confirmability to establish its rigour. Every effort has been made to fulfill the requirements of these criteria at all stages of the study.

5.7 Methodological issues and dilemmas

There are three other important issues to be discussed in relation to this study's methodology. These are researcher bias, the transcription process and the composition of student peer groups in the study.

5.7.1 Personal bias

Like any interpretive research, this inquiry is 'value bound' (Lincoln & Guba, 1985).

The study is bounded by assumptions, theories and perspectives and is regulated by both cultural norms and the researcher's individual beliefs. For example, the focus on the use of computers to enhance the learning process reflects the researcher's personal commitment to the value of technology-mediated learning. Similarly, the use of the program in pairs reflected the researcher's commitment to peer learning.

Under the constructivist paradigm adopted in this study, any assertions made in the findings must be read as an interpretation (or mental construct) of the researcher and therefore not totally alienated from personal bias and personal values. Discussion of these assertions must be read in a similar way. For example, the selection of quotes representing critical incidents in chapter 6 and the discussion of students' understandings from interviews used in chapter 8 were subject to the researcher's interpretation. Indeed, the alternative conceptions discussed in chapter 7 were the researcher's own conceptions of the students' conceptions (Duit et al., 1996). Great care was taken throughout the study to consider these issues when interpreting data: "Much care is necessary in planning, carrying out research and especially in interpretation, in order to remain sensitive to one's own conceptions, ideas, beliefs and prejudices about conceptions" (Duit et al., p. 18).

5.7.2 Transcription issues

Transcription freezes and magnifies the spoken word. The process of transcription creates a new text whose relations to the original data are problematic: "Just the change of medium from speech to writing alters our expectations and perceptions of language" (Lemke, 1998, p. 1176). Transcription can erase information about emphasis, attitude of surprise, irony, humour, emotion, speaker identity, dialect etc. Hence, information about the timing of the speech (e.g., pauses, changes of fluency, simultaneous speech) is important to note in transcription. Indeed, non-lexical vocalizations (e.g., hesitations, repetitions, false starts) can carry meaning and also should be transcribed: "What matters is how words are tied together" (p. 1177). This study recognizes the problematic nature of data transcription and in light of these issues, great care was taken in the transcription of all student and teacher interview data, and critical incidents from students' learning conversations. Wherever possible, non-verbal data (from video tapes) and non-lexical vocalizations were included in the transcripts to add meaning to the text.

5.7.3 Collaboration issues

The composition of the peer groups was an important issue to be confronted early in this study. As discussed in section 4.2.1 the collaborative use of the computer program gives students an opportunity to reflect on their own and others' ideas and negotiate shared meanings in a social setting. These processes are an important part of a social constructivist perspective on learning (Prawat, 1993; Solomon, 1987) and recognize the importance of both personal and social aspects of learning. However, the issue of group size and the process of how students should choose their groups were considered by the researcher in light of relevant literature and in cooperation with the class teachers.

Heller and Hollabaugh (1992) found that groups of three students were optimum for general quality of learning, exposure to a range of views, and opportunities for individuals to contribute. Alexopulou and Driver (1996) also investigated ways in which Greek students interacted in tasks aimed at the construction of physics knowledge in groups of two and four. They found that progress towards meaning-making was significantly greater in groups of four students and there was a constrained nature to the discourse of students grouped in pairs. However, Roth et al. (1996) investigated group work in a computer environment and found that groups of any more than two or three students curtailed appropriate behaviours and quality of talk at the computer. They referred to the obvious limited space in front of the computer as an obvious but important factor in the study. They referred to this factor as the "exclusion dimension" (p. 1008) and discussed how some students in larger groups who had a limited view of the screen were excluded from meaningful conversation in their study: "The computer divides physical space such that it leads to the exclusion of group members from the interaction" (p. 1010). In the light of this literature, it was decided to group students in pairs. This is contrary to recommendations from Heller and Hollabaugh (1992) and Alexopulou and Driver (1996) and indeed may form a limitation to this study. However, the 'exclusion dimension' discussed by Roth et al. (1996) was considered to be important in this particular study and consequently students used the program in pairs.

Students in this study chose their own groups. This was done to maintain the status quo of both class environments. Both teachers promoted similar ways of choosing groups and this policy minimized researcher interventions into the naturalistic setting of each class. Indeed, Hogan (1999) found that students work better with people whom they like and advised that when the main goal of group work is to promote in-depth, higher-order collaborative thinking, students should be allowed to choose their own groups.

5.8 Ethical issues

This study was approved by the Curtin University Human Research Ethics committee during 1998. Permission to use the classes involved in the study was obtained from the school principals and class teachers (refer to Appendixes G and H for copy of letters). Teachers' participation in the project was completely voluntary and they were invited to discuss the research with me at all stages of preparation. Parents of students in the study were provided with a description of the study and invited to contact the principal or the researcher if they had any questions. They also were requested to sign a consent form (refer to Appendix I) and were given the name, phone number, fax number and email address of the researcher. Students and teachers were informed about the nature of the project, the names of the researcher and supervisor, the title and purpose of the study and the reasons for the study. They were informed about the timing and length of interviews and questionnaires as well as their rights during the study. Specifically, they were informed that they could withdraw their participation at any stage of the project.

The names of participating schools remain confidential. Indeed, the real names or other forms of identification of all participants have not been used in documents associated with the research. Pseudonyms are used in this thesis to ensure student and teacher anonymity. All data collected are securely stored on computer disk and the researcher is the only person with access to these data.

5.9 Background on class environments and student attitudes to computers

Two survey instruments were used to gain an insight into the class environments for both classes: the *Constructivist Learning Environment Survey* (Taylor et al., 1997) and a separate survey—*My Attitude to Computers*—that probed students' attitudes to computers. These were both administered to students during the post-computer sessions. Interview data and field notes supplemented insights from these questionnaires.

5.9.1 Rationale for use of survey instruments

Background on Constructivist Learning Environment Survey (CLES). The CLES, which is usually used to monitor the development of constructivist approaches to teaching school science and mathematics, contains five constructs or scales—personal relevance, uncertainty, student negotiation, shared control and critical voice. The survey consists of 25 Likert-type items (five per scale) and exists in two forms. Firstly, the *actual* form surveys student and teacher perceptions of the extant to which they actually perceive their class in each of these scales. Secondly, the *preferred* form that surveys student and teacher perceptions of the extant to which they wish they could see their class in each of these scales (refer to Appendix J). Qualitative and quantitative studies were reported in Taylor et al. (1997) that confirmed the plausibility, statistical integrity and robustness of this instrument.

Rationale for using CLES. Two scales from the CLES were used in this study to gain an insight into the students' and teacher's perceptions of key aspects of their normal science classroom learning environment. These dimensions were chosen because they provide relevant background information concerning both classes in this study and should facilitate the reader's interpretation of relevant findings. These dimensions were the Personal Relevance (or *Learning about the World*) scale and the Student Negotiation (or *Learning to Communicate*) scale. The Personal Relevance scale is concerned with the perceived relevance of school science to students' out–of–school experiences. The Student Negotiation scale is concerned with the perception of opportunities for students to explain and justify their ideas and reflect on the viability of their own and others' ideas in a collaborative setting.

Student and teacher perceptions were an integral part of some findings in this study and an understanding of the relevant background of these students and their teachers (from these two dimensions of the CLES) should benefit the reader's interpretation of these findings. For example, their impressions of collaboration processes during their use of the program were discussed in some of the findings relating to Research Question 1 (refer to chapter 6). Their perceptions relating to contexts used in the POE computer tasks were important foci of the findings relating to Research Question 3 (see chapter 8). Background data from the CLES presented in this section should help the reader gain further insight into these particular findings.

Background on the Attitude to Computers survey. This questionnaire was designed by the researcher to suit the context of this study. It was informed by other similar attitude surveys, for example, the Computer Attitude Scale (CAS) instrument used by Escalada and Zollman (1997). The questionnaire designed for this study consisted of 10 items that covered experience and confidence using computers, perceptions of the computer as a learning tool, and attitude to group work using computers. Each item contained a 5 point Likert-scale and items 3, 5, 7 and 9 from the survey were phrased in the negative and hence were scored in reverse (refer to Appendix K). Mean scores were calculated for each item, with a score of 1 corresponding to the lower end of the scale (*Strongly Disagree*) and a score of 5 corresponding to the upper end of the scale (*Strongly Agree*).

Rationale for using the Attitude to Computers survey. This survey was administered to students to find their general experience with and attitude to the use of computers. As this study involved the use of a computer-mediated intervention, these insights were important to the understanding and interpretation of the findings in this research, particularly the student and teacher perceptions discussed in chapter 8.

5.9.2 Insights into the Year 11 class environment and students' attitude to computers

The students in this class displayed mature peer learning skills but perceived a need for some extra real-life contexts in their learning. There was an impressively trusting and open environment where an 'open discourse' (Taylor et al. 1994) clearly flourished. Most students had a positive attitude towards using computers in the classroom and were familiar with the POE strategy. The teacher of this class was an innovative and highly skilled practitioner who understood and valued constructivist learning principles.

General class environment. The student and teacher perceptions of real-life contexts used in this class (see *Learning about the World* scale) were interesting. There was a medium-sized gap between the students' actual and preferred scores (or 'person-environment' fit) in this section of the CLES (see Table 5.2 and Figure 5.1),

Table 5.2

Individual responses for the Year 11 teacher and class frequencies for the CLES (3 students absent. n=19)

Item	*	Teacher	Class frequencies (students)				
In this class...			Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Learning about the World Scale							
1. I learn about the world outside of school	A	4	0	0	5	11	0
	P	5	0	1	2	8	5
2. My new learning starts with problems about the world outside of school	A	5	0	0	9	5	2
	P	5	0	1	2	8	5
3. I learn how science can be part of my out-of-school life	A	4	0	0	4	8	4
	P	5	1	2	3	4	6
4. I get a better understanding of the world outside of school	A	4	0	0	8	6	2
	P	5	0	0	1	9	6
5. I learn interesting things about the world outside of school	A	4	0	2	4	8	2
	P	5	0	0	1	7	8
Learning to Communicate Scale							
21. I get the chance to talk to other students	A	5	0	1	2	4	9
	P	5	0	0	2	8	6
22. I talk with other students about how to solve problems	A	5	0	0	1	6	9
	P	5	0	0	0	5	11
23. I explain my ideas to other students	A	5	0	3	0	7	6
	P	5	0	0	3	5	8
24. I ask other students to explain their ideas	A	5	0	0	2	7	7
	P	5	0	0	1	4	12
25. Other students listen carefully to my ideas.	A	5	0	1	3	8	4
	P	5	0	0	4	4	8

* A: Actual scores; P: Preferred scores

indicating that this area of their physics learning could be improved. There was a larger gap here between the teacher's actual and preferred scores, indicating that Judy was aware of this issue. (Indeed, such a large gap between teacher's actual and preferred scores is typical of most class environment survey results (Fraser, 1991).) The results for the *Learning to Communicate* scale showed that students generally perceived a pleasing level of opportunities in their classroom for explaining and justifying their newly developing ideas, for listening attentively and reflecting on the viability of their own and others' ideas. This is indicated by the small discrepancy between the students' actual and preferred scores for this scale. Indeed, the teacher had extremely high expectations in this area and her similarly high 'actual' score for this scale indicated a strong emphasis on this aspect of her teaching in this class.

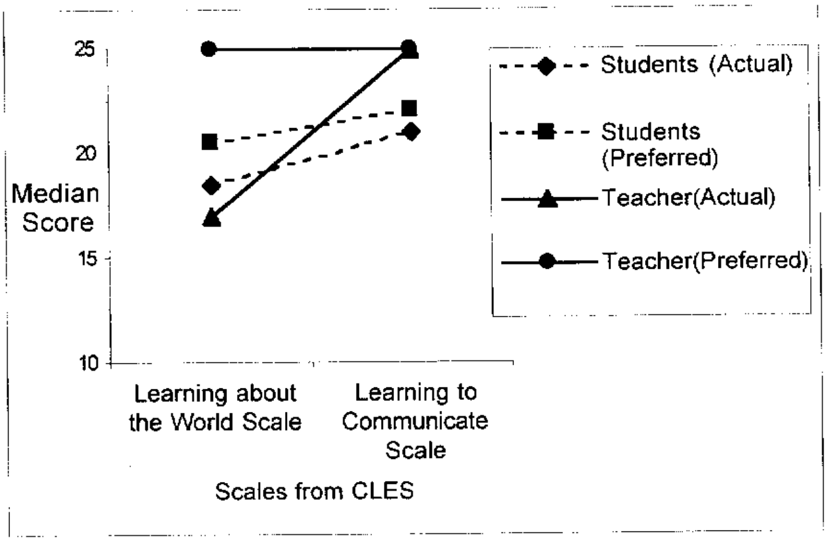


Figure 5.1 Median student and teacher scores from CLES (2 scales only). Scores reflect the Year 11 students' and their teacher's perceptions of their normal and preferred science class environment.

Judy mentioned the importance of discussion and group work in many of her teaching strategies during both informal discussions and formal interviews. For example, during her formal interview, she spoke about her Year 12 class and how they had been conducting a strobe photo experiment. She went on to explain how the students started the session: "At first we discussed what they thought happened to projectiles in flight and then we talked about how they could record the motion of a projectile accurately enough to make measurements...." These data can be triangulated with field notes describing an incident that occurred during an early visit to the school.

> A significant early insight into Judy's teaching practices and indeed the learning environment of her Physics students was gained in a brief 'tour' of her classroom during this initial meeting. She immediately showed me some photographs and posters that her students created and elaborated on how she was using these posters to introduce her students to projectile motion (NB. these were not the students who eventually participated in this study!) She mentioned that the girls made posters in groups before presenting them to the class and discussing them. It was obvious even at this first visit that Judy's students participated in meaningful groupwork and value was placed on the discussion of students' ideas.

These early impressions were later reinforced during observation of Judy's lessons. For example, during one of the pre-computer sessions, students worked in groups using ticker-timer equipment to complete POE tasks. Various groups were asked to give a small 'report' to the whole class at various stages of this lesson, prompting the following field notes entry:

> The classroom climate in Judy's class was observed to be extremely trusting. For example, most students who presented short reports in front of the class (to discuss predictions, reasons etc.) were willing to risk sharing and analysing their quite personal science views in front of the whole class. Students listened most attentively to others' comments during these discussions and they obviously valued each other's opinions.

Similar observations were recorded in field notes made in subsequent lessons:

> Once again the students' comfort with working in groups (of two or three students) was obvious. Most students freely discussed their problems with their partner and when necessary discussed further problems with other groups and the teacher. It was quite common to see groups consulting and checking with other different groups. Students were once again 'on task' for most of the lesson.

Familiarity with the POE strategy. Judy mentioned on numerous occasions that she used the POE strategy in a lot of her class demonstrations. Indeed, students appeared to be quite comfortable with the process during the 'ticker-timer' lesson, displaying an appropriate level of confidence and familiarity with the POE tasks. The students' written responses in the difficult explanation phase of these tasks were impressively detailed. Indeed, their observation skills appeared to be well developed, as noted in the following field notes during this classroom-based observation lesson:

> Students were generally very observant! Some students analysed the actual dots on the tape and their drawings of the ticker tape were most accurate. They often referred to human error and showed a mature appreciation of the scientific process.

Attitude to computers. Students' responses to the survey items and comments made during student and teacher interviews indicated that this class generally held a positive attitude to technology. There were one or two exceptions but most students perceived themselves as confident computer users.

Responses to items 2 and 7 (refer to Table 5.3) from the survey indicated that students generally had positive learning experiences using computers and held

Table 5.3

Responses to items on student perceptions of their attitude towards computers from the questionnaire: My Attitude to Computers. (Three students absent. n=19)

Item	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Perceptions of computer as a learning tool					
2. I find that computers can help me learn	0	0	1	6	9
7. Using computers to help me learn is a waste of time*	8	7	1	0	0
9. The main use for computers at school is to learn computer skills*	0	4	6	6	0
Experience and confidence using computers					
1. I am experienced using computers	1	0	2	8	5
3. I am afraid of computers*	9	4	2	1	0
5. I would prefer to use a pen and paper than type on a keyboard*	2	6	4	1	3
6. I feel confident using computers	1	0	0	9	6
8. I like using computers	0	2	0	4	10
10. My computer skills are very good	1	1	4	5	5
Attitude to group work with computers					
4. I prefer working with another person on the computer	2	3	5	3	3

* Item framed in the negative

positive attitudes regarding the use of computers in the classroom. There were 6 items relating to the students' experience and confidence with computers. With the exception of one student (e.g., refer to items 1 and 6), most students perceived themselves as being generally confident and experienced computer users. Item 4 provided interesting results from the perspective of students' attitudes towards working with other students at the computer. There were a wide range of attitudes here, many students not particularly caring whether they worked by themselves or with another person. Responses to item 8 were significant—the mean score of 4.4 for this item indicated that students in this class enjoyed using computers. Other responses indicated that students generally felt comfortable and confident with computers. This high level of confidence with computers was reiterated by both the teacher and her students in the interviews. For example, Judy mentioned in her informal interviews that most students were most proficient computer users:

> No, I don't know of anybody [who is uncomfortable with computers] in that class. It doesn't mean that there won't be somebody revealed but I don't think there is. In fact it's the other extreme—for example, Antonia is the web master here at school and she does commercial stuff for the school. (From teacher interview with Judy)

When asked about this subject in their interview, one student, Alison, mentioned: "Most [students in the class] would be [proficient]...most people our age are pretty comfortable with computers." Perhaps the most significant responses on the survey were made to items 2 and 7. These items scored the highest mean scores and indicated that students generally perceived computers as a useful learning tool. Interestingly, responses to item 9 indicated that students generally perceived the use of computers in the classroom as more than simply learning computer skills. There was a large variety of responses to item 4—three people strongly agreed with this statement, three students strongly disagreed and many students recorded a neutral response. There were some students in the class who strongly preferred working by themselves with the computer and some who strongly preferred working with a partner. Most students, however, were impartial as to whether they worked with someone on the computer.

In summary, the responses to the questionnaire and data from interviews indicated that the students in this class were experienced and confident users of computers with a mature perception of the role computers can potentially play in the learning process. Hence, it can be assumed that most students in this class participated in this research with a positive attitude towards computers.

Summary of Year 11 class insights. This section provided an insight into a Year 11 physics class at a girls' school in the eastern suburbs of Sydney. Their teacher was a highly innovative science educator who values and implements constructivist teaching strategies in her classes. The dimension of student negotiation was a particularly positive feature of the classroom environment as measured by the CLES. The students in the class displayed effective group skills and were familiar with the predict–observe–explain strategy. Most students were confident and competent computer users and valued the role of computers in learning science.

5.9.3 Insights into Year 10 class environment and students' attitude to computers

A feature of this class was the positive student and teacher perceptions of real-life contexts used in their science lessons. However, opportunities for students to discuss and reflect on others' ideas in collaborative settings were somewhat restricted according to responses to items from the *Student Negotiation* scale of the CLES. This perceived limitation seemed to be influenced by the teacher's concern about curriculum demands and pressure to 'cover the content' of the set syllabus. Almost all boys in this class were experienced computer users who enjoyed working with technology.

General class environment. The 'person-environment' fit for the learning about the world scale was quite positive in the boys' class. The small discrepancy between the students' actual and preferred median scores in this section of the CLES (refer to Table 5.4 and Figure 5.2) indicated that students were generally satisfied with the level of real-life contexts used in their science classroom. However, unlike the girls' class, there was a perceived dissatisfaction concerning the level of opportunities that students received for explaining and reflecting on their own and others' ideas (see learning to communicate scale). There was a significantly large gap between the students' actual and preferred median scores for this scale. Indeed, the teacher perceived an even lower level of student negotiation of ideas as indicated by his low 'actual' score for this section. Class observations were generally in agreement with these perceptions. There was noticeably less groupwork in the non-computer lessons (compared with the Year 11 class) and there was a large amount of teacher-centred

Table 5.4

Individual responses for the Year 10 teacher and class frequencies for the CLES. (Six students absent, n=27)

			Class frequencies (students)				
Item In this class...	*	Teacher	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Learning about the World Scale							
1. I learn about the world outside of school	A	4	1	0	3	9	8
	P	5	1	1	4	6	9
2. My new learning starts with problems about the world outside of school	A	3	0	1	5	8	7
	P	5	0	0	6	7	8
3. I learn how science can be part of my out-of-school life	A	3	1	5	3	6	6
	P	5	0	1	4	8	8
4. I get a better understanding of the world outside of school	A	4	1	1	4	8	7
	P	5	0	2	4	5	10
5. I learn interesting things about the world outside of school	A	4	1	2	3	6	9
	P	5	0	2	6	3	10
Learning to Communicate Scale							
21. I get the chance to talk to other students	A	3	1	0	2	8	8
	P	4	0	0	4	1	16
22. I talk with other students about how to solve problems	A	3	1	3	1	6	10
	P	4	1	0	4	3	13
23. I explain my ideas to other students	A	3	3	2	2	7	7
	P	4	1	1	4	1	14
24. I ask other students to explain their ideas	A	3	2	3	2	6	8
	P	4	4	1	1	3	12
25. Other students listen carefully to my ideas.	A	3	5	0	8	5	3
	P	4	3	1	4	2	11

* A: Actual scores; P: Preferred scores

discussion. However, this observation is in conflict with Wayne's comments made during his interview, where he emphasized the importance of student discussions in his normal classes: "Our science classes are structured so there is a lot of free talk that goes on; a lot of discussion goes on about what's happening."

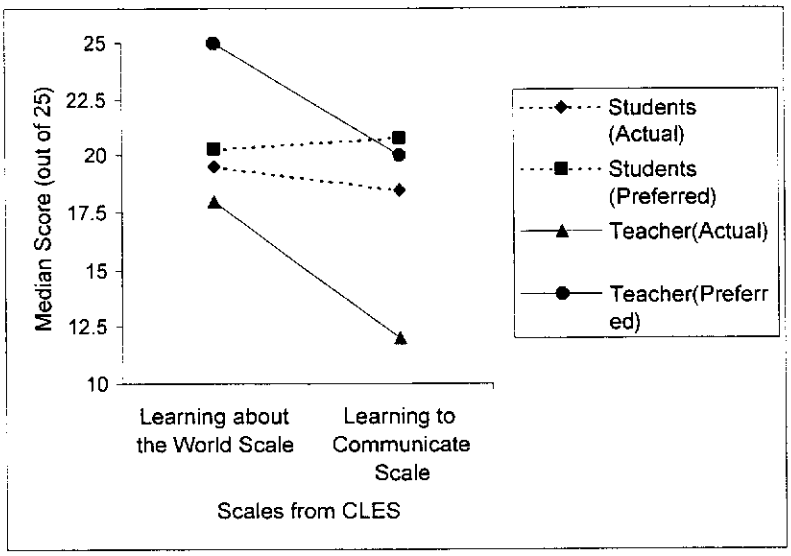


Figure 5.2 Median student and teacher scores from CLES (2 scales only). Scores reflect the Year 10 students' and their teacher's perceptions of their normal and preferred science class environment.

Indeed, Wayne's interest in the collaborative aspect of the computer was recorded in field notes from one of the preliminary meetings with the researcher:

> During our meeting, he emphasised his value of student-centred learning activities and small group discussions and appeared to relate favourably to the 'collaborative probe' function of the computer program to be used with the students. He seemed to be quite interested in this collaborative nature of the program.

The reasons behind this apparent conflict between Wayne's firm belief in peer learning and related perceptions of the class environment were perhaps related to Wayne's strong and frequently expressed concerns about time constraints relating to curriculum requirements. For example, in our interview he reflected on the efficiency of the computer program used in this study and showed a strong concern for curriculum constraints in his teaching program (refer to section 7.1.1). Wayne often mentioned the amount of time needed for effective science teaching. For example, after one of the post-computer classes, he mentioned: "We could take aside 6 months and discuss all the ideas that came about in this lesson." (Indeed, during another informal discussion, he sarcastically used a 'production line' analogy to describe the constraints of the senior physics course: "Physics is like a sausage factory—you take them in and spit them out!") The students themselves appeared to be concerned about similar curriculum issues. For example, during an introduction to the research project in a pre-computer lesson, some boys asked if the project was an assessment test. (The researcher stressed that it was definitely not a test and students were subsequently encouraged to take their time during their use of the program and express their true beliefs in their responses!)

The result of these tensions between curriculum constraints and Wayne's open belief in peer learning seemed to be a sacrifice of opportunities for students to negotiate shared meanings together in collaborative settings. Although the use of rich everyday contexts were a feature of class lessons, there seemed to be a compromise on these collaboration opportunities to compete with increasingly demanding syllabus requirements.

Attitude to computers. Students' responses to these survey items (refer to Table 5.5) and informal comments made during student and teacher interviews indicated that this class generally held a positive view of technology-mediated learning. Most students thought computers were a useful learning tool, although responses to item 9 reflected their uncertainty of the computer's exact role in their learning environment. Other responses reflected a positive attitude towards computers, although interestingly, their item 10 responses indicated a more conservative perception of their competency levels. This general confidence with computers was most evident in their engagement with and approach to hardware and software during the computer lessons. Indeed, Wayne made the following comment in his formal interview: "The boys enjoy computer work...." Responses to item 8 confirmed these beliefs with only 1 student from the whole class indicating that he didn't like using computers.

Like the girls class, there was a mixed response to item 4. Indeed, the majority of boys in this class preferred to work individually at the computer. The reasons for this preference were not investigated but could well be related to the traditional view of the 'computer as tutor' (refer to section 2.3.1).

Table 5.5

Responses to items on student perceptions of their attitude towards learning with computers from the questionnaire: My Attitude to Computers. (Six students absent, n=27)

Item	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Perceptions of computer as a learning tool					
2. I find that computers can help me learn	0	0	3	10	8
7. Using computers to help me learn is a waste of time*	10	6	3	2	0
9. The main use for computers at school is to learn computer skills*	1	5	2	9	4
Experience and confidence using computers					
1. I am experienced using computers	0	0	3	10	8
3. I am afraid of computers*	15	4	1	1	0
5. I would prefer to use a pen and paper than type on a keyboard*	7	6	4	3	1
6. I feel confident using computers	0	1	3	9	8
8. I like using computers	1	0	3	6	11
10. My computer skills are very good	0	2	5	5	9
Attitude to group work with computers					
4. I prefer working with another person on the computer	8	8	2	3	0

Summary of Year 10 class insights. This section has provided an insight into a Year 10 advanced science class at a boys' school in the inner western suburbs of Sydney. Their teacher was a well-respected, perceptive and experienced teacher who promoted the use of real-life contexts in his lessons. Indeed, the *Personal Relevance* dimension was a positive feature of the classroom environment as measured by the CLES. Survey results for the *Student Negotiation* scale, as well as researcher observations and interview data, indicated that improvements could be made to some of the collaborative learning strategies used in the class. Almost all students had a positive attitude towards computers, although they generally preferred working at the computer individually.

5.10 Conclusion

This dual case study is informed by an interpretive methodology. Mainly qualitative but some quantitative data were collected from as many different sources and perspectives as possible. Aspects of credibility, transferability, dependability and confirmability were applied to data collection and analysis procedures, and the findings from this research aim to satisfy these conditions of a rigourous interpretive study. Most students were familiar with the POE strategy, displayed competent computer skills and held generally positive attitude towards technology-mediated learning. The classes' background information outlined in this chapter is designed to facilitate reader interpretations of findings in subsequent chapters.

CHAPTER 6

THE STUDENTS' LEARNING CONVERSATIONS AT THE COMPUTER

6.0 Overview of chapter

This chapter focuses on the student discussions that took place during their engagement with the predict–observe–explain tasks. Social constructivism is used as a theoretical framework (refer to section 2.2.2) to analyse these learning conversations and address the main research question relevant to this chapter (given below), along with three subsidiary research questions:

Research Question 1:
To what extent do the computer-mediated POE tasks promote meaningful discussion about students' science ideas?

Subsidiary questions:
I. To what extent do the students articulate, justify and reflect on their own ideas?
II. To what extent do the students reflect on the viability of their partner's ideas?
III. To what extent do the students co-construct ideas and negotiate shared meanings?

Discussion directed by these research questions is based around four assertions and is supported by quoted learning conversations representing critical incidents that occurred during the computer sessions. Claims also are supported by data from interviews, survey responses and class observations.

6.1 Assertion 1: The computer-mediated POE tasks encouraged most students to articulate and justify their own conceptions

Most groups of students attempted to articulate their ideas and thoughts as they formulated and edited their written or drawn predictions and gave reasons for these predictions. Students often justified their views as they debated their responses. Data from student and teacher surveys and interviews supported these claims.

6.1.1 Discussion of critical incidents

The rich contexts encouraged the students to reflect on and articulate their ideas relevant to the problems posed. The high incidence of students editing their written and drawn predictions was testimony to these meaningful discussions. However, a limited science vocabulary sometimes impeded full articulation of ideas.

Dave explained his thinking to his partner when predicting which ball would hit the ground first in task 13 (Two Falling Balls). In this task, two balls are launched from a given height simultaneously. One is launched horizontally and the other falls vertically from rest. Dave tried to support his explanation with his own theory about the fastest route between two points:

Dave: That one I reckon, don't you?
Pat: Yes, the ball on the right. (i.e., the ball falling vertically)
Dave: Because that one (ball launched horizontally) has been propelled upwards and then it can go down where as that one (the ball falling vertically) is just going straight down and is less...and also I reckon the fastest gradient between two points is a straight line...
Pat: I agree.

Although Pat was the dominant person in this group, he was in agreement with his partner and seemed to appreciate Dave's effort to articulate his thoughts.

In a separate incident, Sam reflected on the amount of gravity on the moon in task 9 (The Astronaut). In this task, an astronaut on the moon drops a hammer and a feather from shoulder height. Sam initially believed that that the hammer would hit the ground first but, being unsure of the conditions on the moon, he paused to think about and question his ideas on the amount of gravity on the moon:

Laurie: What do you think?
Sam: Oh—the hammer!
Laurie: I say both.
Sam: Is this on the moon?
Laurie: Yeh.
Sam: OK—both at the same time. Because there's no gravity on the moon.
(Pause)
There's no gravity?
Laurie: Yes—a little bit.
Sam: Oh that's right.

Sam reflected on his initial intuition that there was no gravity on the moon. He questioned his partner about this and then needed little persuasion to reconsider his preconception.

Alison and Jessica tried to find a reason (although a partially incorrect one) for their prediction that the ball would land back in the moving cart in task 14 (Cart & Ball I). Interestingly, Jessica started the conversation by asking for her partner's explanation but then proceeded to form her own explanation.

Alison: It'll go back into it, do you think? Back into the tube. Do you think?

Jessica: Probably. (Uncertain) Explain it!

Alison: Oh, I don't know how to explain it. Because…

Jessica: (Interrupting) Because the cart's moving and the ball is moving…

Alison: (Interrupting) No, because…

Jessica: (Interrupting) Because the cart is exerting a force on to the ball!

Alison: Yeh, yeh.

Jessica: Yeh. Until the gravity acts on it and pulls it back down again.

Although Alison's contribution was minimal here, her mere presence seemed to initiate some deep thinking by Jessica about the problem.

Teacher intervention sometimes mediated students' articulation of ideas, particularly in class 1. (See chapter 9 for a more extensive discussion of the teachers' perceived roles in the sessions.) For example, Judy spoke to Kirstie's group towards the end of the session and prompted Kirstie into explaining her thoughts on the conceptually challenging cart and ball tasks:

Kirstie: What did you think of this one (task 15)—behind or in front (of the cart)? Or in it?

Teacher: I think behind.

Jenny: That's what I thought for task 14.

Teacher: On the flat, it should land in it.

Kirstie: Should it?

Teacher: Mmm…

Kirstie: (Articulating her ideas) But look, you shoot it upwards and it's travelling at a constant speed, you'll think that…see it goes straight up and straight back down but this time it's travelling at a constant speed it should be up and this (the ball) should have finished moving.

Teacher: But down the slope (in task 15) the cart accelerated even more.

Jenny: But so is the ball.

Teacher: Why?

Jenny: Because the angle it's projected.

Teacher: Interesting idea.

Jenny's final comments here were most perceptive and revealed an advanced understanding of this complex scenario in that she was aware of the ball's motion and its relationship with the cart.

Students often disputed each other's ideas, giving group members a chance to justify and defend their views. This usually occurred during the prediction or observation stages of the POE strategy. Laurie chose to justify his reasoning in task 12 (The Sailing Boat) after his partner disagreed over the prediction that the ball falling from the moving sailing boat would land at the foot of the mast. However, Sam remained unconvinced with Laurie's ideas:

Laurie: It's B. (i.e., directly below the mast of the sailing boat)

Sam: Well, the boat's still moving (disagreeing with Laurie's prediction)

Laurie: Yeh, but the ball is part of the boat. Like the ball will move (forward) as well. (Defending his own views)

Sam: I reckon it will fall, because the boat is moving faster. I'm going to predict A. (i.e., behind the mast)

Cath and Michelle disagreed with each other in task 8 (The Swing). In this task, a boy is moving forward on a swing and passively releases a ball. After stating her disagreement with her partner, Cath defended her view by explaining her reasons:

Michelle: I think...so he's travelling up, then just lets it go so I think it (the ball) will just go straight down wouldn't it?

Cath: Even though he's not...the whole swing motion has been executed.

Michelle: But he's not throwing it; he's bringing it forward and letting it go...but it'll go forward so it'll go like this wouldn't it? (Michelle shows Cath the drawing of her predicted pathway that depicted the ball moving forwards before falling vertically downwards) Maybe a bit sharper.

Cath: No I don't think that's right. Because the swing is still moving so it's giving the ball a bit of (forward) velocity. (Defending her own views)

Michelle: OK. (In agreement)

Pat and Dave also had a small dispute over the drawing of their predicted pathway of a slow ball rolling off a table in task 4. Dave's disagreement with Pat's prediction eventually caused Pat to justify and defend his view. The students edited their drawing on numerous occasions during this process:

Pat: It's going to go down more than out.

Dave: No. My prediction is it's going to go down heaps faster. It'll go out a little bit and then go down. Not much though. How do you like that? (Dave makes a draft drawing showing the ball moving a considerable distance from the table)

Pat: But the thing is it's going slowly—go back a bit—I reckon it's going a lot slower than that Dave.

Dave: Like that? (Dave now edits the drawing, effectively reducing the predicted horizontal range of the projectile)

Pat: Yeh—I reckon it's more like that Dave.

Dave: Oh yeh—OK. (Not quite convinced)

Pat: It's going so slow, it'll only get pushed out from the table a little bit before it goes down. (Defending his own views)

Indeed, many of the tasks requiring students to respond in a drawing format initiated rich discussions. In this sense, the drawings acted as 'conversational artifacts' (Pea, 1993). Perhaps this was due to the challenging task of describing these trajectories in the students' everyday language or perhaps it was because the outcome required close analysis and interpretation of the video clips. Joan and Leigh had a small disagreement during their task 8 (The Swing) prediction. As they defended their views, their drawing became a focus of their discussion:

Joan: What's he going to do, throw it or drop it?

Leigh: He's going to release the ball. Let's look at the preview.

Joan: Yeh—he's still travelling forward. Let's see that again (the preview)... I think it'll go up a bit then go down.

Leigh: Well it's dropped so it'll go in a bit of a curve.

Joan: Up? No... (Thoughtfully)

(Pause)

Leigh: Sort of from there. (Pointing to the drawing)

Joan: What do you mean?

Leigh: It won't go up. It'll sort of go...(drawing path) as it goes down.

Joan: Do you think? (Obviously disagreeing) I thought it would keep going up for a bit and then go down! (Tracing a path on the drawing with her finger)

Leigh: (Defending her view) Because he drops it right?

Joan: Oh yeh—he just drops it doesn't he! He doesn't throw it. OK then. (Sounding convinced)

(They again edit their drawing)

There were numerous incidents where groups changed their drawing up to three times in either the prediction or observation stages. This high incidence of students editing their drawings was testimony to these meaningful discussions and indeed, many of the critical incidents quoted in this chapter feature the students' drawings as a 'backdrop' to their conversations.

Although many students attempted to explain their views, choosing the correct science jargon in order to articulate ideas and views was a real challenge for many groups. For example, Anne had trouble finding suitable words as she tried to predict which ball would hit the ground first in task 13 (Two Balls Falling):

Anne: This one (will land first), the ball on the right.
Jane: Yep.
Anne: Because it has downward motion whereas the other one has sideward motion which is slowing it down—downwards, that way. (Laughter)
Jane: I know what you mean! Well that's going to take longer because its acceleration is horizontal...
Anne: (Interrupting) Whereas the other one's acceleration is downwards...Yes, I know what I mean. I just don't know how to say it.
Jane: Yes I hate that.

As these students were at the start of their physics course they had little experience in attempting to describe two-dimensional motion. Without realising it, Anne chose the words *downwards* and *sideways* to represent the vertical and horizontal motion, respectively, but still had trouble describing her prediction. The term *range* was introduced to students in task 16 (The Hose) on the introductory page. Jilly and Rochelle eventually used this new word in the context of this task. As Jilly was searching for the correct word to describe the horizontal distance covered by the water emerging from the hose, her partner helped her with the dilemma:

Jilly: Should we talk about how it decreased? After that angle (of projection), it decreased.
Rochelle: The angle decreased.
Jilly: After C, the length of the water...
Rochelle: Ah the...
Jilly: The...
Rochelle: The range!
Jilly: Yes the range.

It must be noted that the introduction of new vocabulary (the term *range*) in task 16 was an exceptional case in the design of this program (refer to chapter 4). In general, great care was taken to use science vocabulary with which the students would be familiar (e.g., the terms *speeding up* and *slowing down* were used instead of the word *acceleration* throughout the program).

6.1.2 Teacher and student perceptions

Teachers' survey data revealed similar perceptions of meaningful discussions between students at the computer (refer to Table 6.1). Responses to items 1 and 74 in particular reflected positive perceptions of the students' learning conversations. Both teachers agreed that the POE computer tasks facilitated students' articulation and clarification of ideas (see items 16 and 53) and also initiated debates about these views (see items 2 and 61). Judy reflected on such occasions during her interview: "There was heated discussion about the projectiles." Indeed, she believed that her observations of these conversations helped her to gain a good understanding of students' views during the computer sessions (also see section 8.1). In his interview, Wayne also chose to reflect on the students' conversations at the computer. He referred to their discussions more generally but in a similar positive tone: "They [the students] liked being able to discuss and think and actually being able to confront the questions...." Later in his interview, he mentioned: "There was relatively unbroken long periods of time that they worked together on successive tasks and I think that just generated a lot more talk—it was on the subject and it didn't waiver." Wayne believed the students themselves appreciated the opportunity to talk to each other about the tasks: "They wanted to talk between

Table 6.1

Teachers' responses to items relating to student articulation and justification of ideas from the survey: Reflections on the POE computer tasks (n=2)

Survey Item	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
1. The program encouraged students to talk about their own ideas					*Judy* *Wayne*
2. I noticed some group members had conflicting ideas.				*Judy*	*Wayne*
16. I noticed many students explaining motion concepts to their partners.				*Judy* *Wayne*	
48. There was too much "off task" talk.	*Judy*	*Wayne*			
51. Most students seemed to express their ideas freely to their partners.					*Judy* *Wayne*
53. The program helped students to clarify their own ideas.				*Judy* *Wayne*	
61. Some group members were arguing about their responses				*Judy* *Wayne*	
74. There was a high level of meaningful conversation between the students as they used the program					*Judy* *Wayne*

themselves about what was on the screen. It was as if the pair and what was happening there was the thing of significant importance [to the students]."

Students also perceived that meaningful discussions occurred during the computer sessions (see Table 6.2) and agreed that the POE computer tasks encouraged them to talk about and debate their ideas (e.g., refer to responses to items 1 and 2).

Table 6.2

Responses to items about student perceptions relating to articulation and justification of ideas from the survey: My Experience Using the POE Computer Tasks (n=46)

Item	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
1. The computer tasks encouraged us to talk to each other about our ideas	1	1	1	27	16
2. We sometimes argued about our responses.	1	7	8	27	3
28. Talking to my partner during the program helped me to clarify my own ideas about motion.	0	3	5	31	7
49. I often explained my own ideas to my partner.	0	1	9	29	7

The responses to item 28 indicated that most students appreciated the opportunity to work with a partner in order to clarify their own views. In their interview, Jessica and Alison reflected on an argument they had about the outcome of task 16 (The Hose):

Jessica: I liked the one with the hose because I think we had an argument about it.
Alison: Yeh...
Jessica: We changed (our prediction) three times.
Interviewer: What was the argument about?
Alison: The hose—which one (pathway) would go furthest? It wasn't an argument, it was just a discussion.
Jessica: Yeh—we just had this big discussion!
Alison: We just kept getting confused and then we would go: 'Oh no! Go back!' We changed it three times.
Jessica: We changed it a whole lot of times because we thought about it a lot.
Alison: Yeh...
Interviewer: You obviously differed in your answers between each other, how did you work out a solution—like a common answer?
Alison: We were just confused...
Jessica: After we talked about it for a while, the person who was wrong would go: 'Ok, you must be right.' ...there wasn't really a dominant person.
Interviewer: Did someone convince the other person that they were right?

Jessica: Not always, it was just more talking about it and a lot of thinking about the problem.

This interview extract showed that both students had an impressive awareness of their own group processes during the computer sessions. They recognised the value of the arguments that occurred as they interacted with the POE tasks and recognised that these conversations led to a deeper level of thinking and problem solving (or in Jessica's words: "a lot of thinking about the problem").

6.1.3 Summary

Students articulated their own ideas relevant to the various scenarios, and debates about predictions and outcomes were common. Student drawings were important foci in some of these conversations and students often edited their pathway predictions during such discussions. In this sense the drawings acted as 'conversational artifacts' (Pea, 1993). Articulation of ideas was sometimes impeded by a limited physics vocabulary, particularly when trying to describe aspects of projectile motion. Teachers also perceived meaningful discussions occurring during the sessions and students appreciated the opportunity to clarify their own views with their partner.

6.2 Assertion 2: The POE computer tasks encouraged most students to reflect on the viability of their partner's conceptions

There were many incidents where students demonstrated mature and thoughtful listening skills as they evaluated their partner's ideas relating to the POE task. Silent pauses in the conversation and frequent questioning of students' views were a feature of these incidents. Task video clips served as a focus for the reflections occurring during the observation phase of the POE tasks. Interview and survey data revealed that most students felt they had listened attentively to their partner during the sessions. From the teachers' point of view, Judy had more positive perceptions than Wayne in this section of the study.

6.2.1 Discussion of critical incidents

The students' engagement with the POE tasks initiated some quality conversations leading to students reflecting on each other's ideas. Students were enthusiastic in listening to and evaluating their partner's views. Student gestures and 'off–computer' mini-experiments also featured in some of these incidents (but will be discussed in more detail in section 6.3).

Jessica and Alison conducted an in-depth conversation about the outcome of task 1 (Falling Ball). Although the task was probably the most simple of all 16 tasks in the program, both students made meaningful reflections concerned with the scenario of a ball being dropped to the ground from a height of about 2 metres. In the process of trying to articulate a reason for their prediction, they changed their actual prediction three times. (As in the drawing tasks, this was a common occurrence with many groups who were frequently seen using the back button to change and edit their responses.) Jessica initially challenged Alison's prediction that the ball would speed up:

Jessica: What are our reasons for this prediction? (They had predicted the ball would increase its speed)
Alison: I know but I can't explain it. It's because it falls and gets faster. (Laughter)
Jessica: Why doesn't it go at a constant speed? Because if I drop my pencil case. Look!

(Alison repeatedly drops her pencil case on to the floor)

Jessica performed a mini-experiment at this point to check the viability of her partner's ideas. She repeated this numerous times and both students reflected thoughtfully on what they saw. Alison began to make analogies with phenomena in space! Jessica again reflected on the viability of her partner's ideas here by asking pertinent questions of her partner:

Alison: Because it's getting closer to the ground. And there's more gravity. (Stated in an excited tone)
Jessica: Is there?
Alison: Yeh well there's more gravity closer to the ground than there is further away from the ground. That's why you 'spaghettify' when you fall in a black hole.
Jessica: Right, OK. I know that up there in space there's not. But just because—does that mean that there's more gravity where my feet are compared to where my knees are?
Alison: Yep.
Jessica: Really?
Alison: That's why you 'spaghettify' when you fall in a black hole; because the gravity is so strong—you go whoop! Because there's so much more gravity here than there is here. (Pointing to her knees and feet)
Jessica: Oh, OK (reluctantly) Well. We need to give a reason, lets see.

Jessica was still not satisfied at this point. She wanted to go back to the prediction page and change their response to 'constant speed'. She eventually made this change, at which point Alison reflected on the viability of Jessica's ideas!

Alison: I don't know, I'm not sure why.
Jessica I think it would go at the same rate.
Alison: Well change it then. (Alison seems to becoming a little uncertain of her own black hole theory now)
Jessica: OK. We'll change it then. (They then go back to their prediction and choose constant speed instead. Alison is reluctant)
Alison: Why would it fall at constant speed but?
Jessica: Because it's not a very long distance?
Alison: (Reluctantly) All right.
Jessica: No no. We'll talk about it. If you disagree with me...
Alison: I don't get it but—I'm not sure. I don't know why would it fall at a constant speed.
Jessica: I don't know. (Pause) Um...well I guess the acceleration will get faster. You know.

After all this interrogation by both group members, they changed their answer back to 'speeding up'. Jessica tried to articulate her thinking as she typed in her response:

Jessica: The ball will get faster because the acceleration will increase because of the gravity as it gets closer to the ground. (Reading as she types)
Alison: That sounds good. Is that all right with you?
Jessica: Yeh. (In an unconvinced tone of voice)

As they proceeded to the movie, Jessica revealed a sense of anticipation in finding out the correct answer. Still unsure about their prediction, she stated: "Either way this could be a learning experience—we'll find out why!" This rich conversation from Alison and Jessica focussed on the simple scenario of a child dropping a ball! In the course of this conversation, the students changed their prediction three times, performed a mini-experiment, hypothesized about the nature of gravity on earth, asked each other many questions and interrogated one another's views.

Dave reflected on the views of Pat during the prediction and reasoning stage of task 12 (The Sailing Boat). The task involved predicting how a ball would fall after being released from the top of a mast of a boat moving at constant speed. Students were asked whether the ball would land behind, below or in front of the mast.

Dave: You really don't know because it'll go forward and it'll drop down
(Pause)

Pat: Yeh. But it (the ball) is going at the same speed (as the boat) Dave.

Dave: Yeh. (Listening carefully)

Pat: If it's going at the same speed as the boat, as it falls, it should land at B.

Dave: Yeh but as it falls like...

(Pause)

Pat: It won't fall backwards. (Sensing Dave's thoughts)

Dave: Does it lose any (horizontal) speed as it falls?

Pat: No it won't

Dave: As it goes forward? (Continuing thoughts from previous question) I reckon A. (Option A is 'behind' the mast)

Pat: No way. We'll soon see.

The silent pauses were significant and indicated that both students were considering each other's viewpoints. Dave finally decided to disagree and stay with his intuitive ideas that the boat would continue to move forward and leave the ball behind. Although there was no negotiated meaning-making here, there was evidence of both students listening and reflecting on each other's views.

Similar reflective silence was evident in a conversation between Cath and Michelle in task 3 (Ball Launch). Again the students' drawing became a focus of the discussion as they attempted to describe the pathway of the ball during their observation of the video clip. (In this task, a person throws a ball horizontally from approximately 2 metres off the ground.) Michelle initially disagreed with Cath's drawing. After evaluating each other's ideas, both students attempted to provide a detailed description of the ball's pathway. In particular, Michelle tried to justify her own idea that the pathway was steeper than the pathway that Cath had observed.

Cath: OK—play it (the video clip) again.

Michelle: When she throws it, it sort of comes up a bit and then comes down. Do you think or not?

Cath: Um...(pause) Well she throws it underarm, she doesn't throw it straight out...OK.

(Long pause as students watch another replay)

Michelle: See it sort of goes up, then it comes down. (Drawing picture)

Cath: It curls up just a tiny bit, maybe not up like that. (Pointing at Michelle's drawing) When it starts to drop a bit, it comes down more gradually.

Michelle: Isn't it more than gradually; it's a bit more than gradual!

Cath: Ah...(Pause as students again watch the video clip)

Michelle: Don't forget she's a lot higher.

Cath: That's all right, we'll change it.

Another feature of this incident was the students' use of the video clip as a 'backdrop' to the conversation. The students frequently used the replay and slow motion facilities to help them closely observe the pathway of the ball (see also section 8.2) before formulating their arguments.

6.2.2 Teacher and student perceptions

Judy's survey responses to items 8 and 71 (see Table 6.3) indicated a more positive outlook than Wayne in this section of the study. She believed that her students had listened carefully to their partner's views. Wayne's perception was slightly different as indicated particularly in his neutral response to item 71. Students' survey and interview responses showed that most students felt that they had learned something from listening to their partner's views. As shown in Table 6.4, responses to item 17 indicated that most students believed they had listened attentively to their partner's ideas during the computer sessions. Although item 34 attracted a range of results, the

Table 6.3

Teachers' responses to items relating to students reflecting on their partners' ideas from the survey: Reflections on the POE Computer Tasks (n=2)

Survey Item	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
8. Students seemed to ignore one another's views.	*Judy*	*Wayne*			
71. Some students seemed to be quite aware of their partner's views.			*Wayne*		*Judy*

Table 6.4

Responses to items on student perceptions relating to reflection on their partners' ideas from the survey: My Experience Using the POE Computer Tasks (n=46)

Item	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
6. My partner's views were of no interest to me.	25	16	3	1	1
15. I often challenged my partner's ideas.	1	8	12	22	3
17. I learned a lot from listening to my partner's views.	2	5	14	22	3
34. I tried to change some of my partner's ideas	1	14	4	24	3
57. I listened carefully to my partner's ideas.	1	2	1	37	5

majority of students felt they had tried to persuade their partner to change their ideas—indicating they had at least considered their partner's viewpoints. Indeed, Anne chose to make the following optional comment in her survey: "It was a very interesting experience and I learned a lot by working one on one with my partner and the computer. It was helpful hearing her ideas and comparing them with my own." Anne's reference to the computer here seems to give the computer a certain status in the learning environment and fits in well with Brophy's (1995) model of computer-mediated collaborative learning (refer to Figure 2.1). During her interview, Kirstie commented on the way she compared her ideas with her partner's ideas:

> I think her reasoning is very well behind things—like she won't say something just on the spot. She has to have the reasons behind it and say 'I think this because...' and then you think 'oh yeh'. Then you consider her's against what you thought would happen. Like sometimes her's would be more logical, sometimes mine would be more logical. (Student interview with Kirstie)

Similarly, Pat reflected on the advantages of working with his partner Dave during the sessions. In his interview, he mentioned: "There was a lot of benefit hearing about another person's insights—about what they thought—and sometimes you can change what you think—or they can convince you."

6.2.3 Summary

Students listened attentively to their partner's views, initiating reflection on the viability of these conceptions. Significant reflective pauses in the conversations as well as engaging questions were a feature of these incidents. Video clips served as a 'backdrop' for these reflective discussions that occurred during the observation phase of the POE tasks. Most students felt they had listened attentively to their partner during the sessions. Learning conversations quoted in subsequent sections provide further examples of this reflection leading to students considering the viability of their own ideas (refer to section 6.3) and in some cases, negotiated sense-making (refer to section 6.4).

6.3 Assertion 3: The POE computer tasks encouraged many students to reflect on and test the viability of their own conceptions

A feature of the students' conversations was the frequent use of hand gestures and the performance of mini-experiments, particularly during the prediction and reasoning stages of the tasks. These physical actions were often collaborative and provided evidence of students reflecting on and testing their own ideas. Surprising outcomes also initiated meaningful discussion, sometimes leading to students reconsidering their own views. Survey data showed that most students believed they had changed some of their ideas as a result of their conversations at the computer.

6.3.1 Discussion of critical incidents

A notable aspect of the students' engagement with the POE tasks was the frequent use of 'off-computer' mini-experiments by groups. Objects such as coins, pencil cases, pencils and pieces of paper were constantly being thrown into the air, dropped on to the floor or rolled off tables! Melissa, Belinda and Joanna's discussion in task 2 (Rising Ball) was typical of these dynamic and meaningful conversations. During the prediction phase of this task, Belinda performed a mini-experiment to help her group predict the motion of the ball thrown vertically into the air.

Melissa: It'll go faster then it will stop at the top and then fall down.
Belinda: I don't think it will go faster.
Joanna: I think it'll go very fast at the beginning and then slow down and stop before it comes down. I don't know.
Melissa: I think it definitely won't because...
Joanna: (Interrupting) Which one should we type?

(Belinda performs an impromptu mini-experiment by tossing her pencil case vertically up into the air. This is followed by much laughter)

Belinda: Oh! What did that look like? What did that look like?
Melissa: Do it again!

(Belinda again tosses up her pencil case. This time all students look closely)

Belinda: What did that look like?
Joanna: It sort of looks like it didn't keep still and then it stopped and came down.
Melissa: Yeh. It came down really fast.
Joanna: Type 'other'! (The 'other' option was one of the multiple choice distractors)
Belinda: Yeh.

Although this was a relatively simple linear motion task, this group devoted a lot of time and consideration to their prediction here. After some conjecture over the outcome, Belinda's repeated mini-experiment (with her pencil case) seemed to focus the group's thinking. (Indeed, most mini-experiments occurring within other groups were also repeated at least twice!) It also was interesting to note that although these students were considering this motion for the first time, Joanna was observant enough to see that the pencil case came to rest as it reached its maximum height. There were many other examples of students conducting 'off-computer' mini-experiments to test the viability of their own views. Some of these are included in descriptions of critical incidents in other sections of this chapter (e.g., see Jessica and Alison's task 2 prediction in section 6.2 and Anne and Jane's task 4 reasoning in section 6.4)

Just as noticeable was the use of hand gestures by students as they articulated and reflected on their thoughts. The following text was an entry into the researcher's field notes from the Year 10 class: "Many boys can be seen pointing to the screen to trace pathways of objects with their fingers or their pen. There are frequent gesticulations in each group." The conversations occurring at these times indicated that students were using these gestures to enhance reflection on their ideas. This was particularly evident during tasks requiring a drawing response. For example, Jenny and Kirstie used hand gestures to help them predict what would happen when a ball rolled slowly off a table in task 4:

(Using the real table in front of her, Jenny repeatedly traces the imaginary path of a ball rolling off it)

Jenny: It's the exertion of the force of gravity on it.

Kirstie: Yeah, but it's got the table too – before it falls to the ground. (Kirstie also uses hand gestures to trace out in the air an imaginary path of a ball falling from a table)

Jenny: (Speaking slowly and thoughtfully) Um...because – it's only got the force. OK, there's a little force placed on it from that direction (sideways) which means that the force of gravity will have more effect on it, so it will go straight to the ground.

Kirstie: Yep. I agree. (Still tracing their predicted pathway with her hand)

Jenny: It'll go straight to the ground because it's got more force on it.

Other examples of gestures and mini-experiments are included in numerous critical incidents quoted in this chapter.

Students sometimes compared previous tasks to help them formulate responses and reflect on their ideas. It was difficult to assess if students had actually accomplished some meaningful learning from these previous tasks or if they were simply rote learning previous task outcomes. The following conversation would indicate the former. During their reflections in task 12, Cath and Michelle cleverly compared the passive launch of this task with the context of the cup and ball exercises (tasks 10 and 11) completed previously. Michelle initiated the comparison with the cup and ball tasks before Cath elaborated.

Michelle: I reckon it'll land in position C. (Stated confidently)

Cath: Wouldn't it hit the mast? I say A (behind the mast); the boat is moving forward.

Michelle: But so was the girl. (Referring to 'the girl' from tasks 10 and 11 video clips)

Cath: Oh OK.

Michelle: Well the other two (tasks 10 and 11) were wrong and we said B.

Cath: Maybe B then. Because—OK— the boat's moving. Before (in tasks 10 and 11) the ground wasn't moving (she says excitedly) and it landed there. Here the boat is moving so it is going to land there. It (the ball) is going to move that way (forward) but the boat's going to move forward too. You know what I mean? B is going to be like C on the ground before. (Referring again to tasks 10 and 11)

Michelle: OK. Choose B—choose B. I know what you mean—I know what you mean.

It is interesting to note here that Cath and Michelle initially disagreed with each other over the outcome of this task. Michelle's remark comparing task 12 to previous tasks seemed to change Cath's views considerably, to the point where she was elaborating on Michelle's original hypothesis!

The observation phase of the POE tasks often produced the stimuli for students to critically review their ideas, especially if their prediction was incorrect. Leigh and Joan were surprised when they saw the hammer and the feather reach the moon's surface at the same time in task 9. Leigh was inspired to review her thoughts:

Leigh: What do you know!

Joan: That's amazing! Obviously the gravity isn't that strong.

Leigh: Does everything fall at the same rate in a vacuum? Does it?

Joan: Yeh—because it (the moon) doesn't have gravity.

Unfortunately, Joan compounded the problem by giving an incorrect reason here. However, in the context of this study, such incidents were most valuable (especially if they were recorded as written responses), as they provided an opportunity for the teacher to assess common alternative conceptions. Similarly, Anne reviewed her thinking quite accurately after unexpectedly seeing the ball land back into the cart in task 14.

Anne: Oh—there is something wrong about this!

Jane: OK.

Anne: Oh yeh. Because the cart's going 'bip' (forward) so that the ball's actually moving at the same forward motion of the cart.

Jane: Oh yeh!

However, surprising outcomes did not always initiate such conversations where students reflected on the viability of their own ideas. Some students simply conceded that they were wrong and made unsatisfactory attempts to explain an unexpected outcome. Indeed, this explanation phase is the most challenging stage of the POE strategy (White & Gunstone, 1992) and further comments regarding this phase in the context of this study are made in section 9.2.1.

6.3.2 Teacher and student perceptions

Only a couple of items from the teachers' survey related to this section (see Table 6.5). Both teachers agreed they had witnessed some students changing their view during their peer discussions—indicating some student reflection on the viability of their own ideas. Only one item from the students' survey was related to this section (see Table 6.6). Most students felt that they had changed some of their ideas as a result of the learning conversations with their partner. Indeed, Jessica and Alison commented on this issue in their interview:

Table 6.5

Teachers' responses to items relating to students reflecting on their own ideas from the survey: Reflections on the POE Computer Tasks (n=2)

Survey Item	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
30. I noticed some students changing their ideas as a result of their discussions with their partner.				*Judy* *Wayne*	
36. I noticed a few students changing their own ideas.			*Wayne*	*Judy*	

Table 6.6

Responses to items on student perceptions relating to reflection on their own ideas from the survey: My experience Using the POE Computer Tasks (n=46)

Item	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
3. I changed some of my own ideas after talking with my partner.	1	3	5	33	4

Alison:	We sort of learnt from each other.
Jessica:	We were both inputting things.
Alison:	We would have a conversation about it and then we realised who was right.

Jessica: The thing is that we had different views and we would talk about it and figure it out...

Later in the same interview, Alison stated:

> I think because we were both working together, it made us think about the things a lot more because we had differing opinions, so we had to think about the problem a lot more. But if we were just by ourselves, we'd go: 'oh yes—that's right because I'm me!' (from student interview with Alison and Jessica)

These perceptive comments showed their appreciation for each other in the collaborative decision-making processes encountered during the computer sessions. The students obviously valued each other's ideas and used them to reflect on the viability of their own conceptions.

6.3.3 Summary

The frequent use of hand gestures and the performance of 'off–computer' mini-experiments were a feature of the students' engagement with the tasks and provided evidence of students reflecting on and testing the viability of their own views. In this sense the POE tasks served as a "deictic and gestural resource" (Roth et al., 1996, p. 1001) to the students' interactions. Many groups experienced surprising outcomes from various tasks, initiating quality discussions about students' views. Survey and interview data from students and teachers supported the assertion made in this section.

6.4 Assertion 4: The POE computer tasks sometimes encouraged students to co-construct new ideas and negotiate shared meanings with their partner

Although there were many examples of strong reflection on students' ideas, examples of genuine co-construction and negotiation of new ideas were less frequent. This may have been because of the time constraints on the students or perhaps a general lack of confidence in the language or 'register of science' needed to undertake such a collaborative process. However, a few groups did provide strong evidence of student negotiation and reformulation of ideas.

Alison and Jessica conducted an in-depth discussion over their predicted outcome of task 12 (Sailing Boat). Many groups were challenged by this task and some interesting discussions emerged here. Alison initially reflected on the viability of her partner's comments before expressing her disagreement over the possibility of a force exerted on the ball as it is released from the mast of the moving boat. Both students then tried to justify and defend their own views:

Jessica: It'll go that way.
Alison: Yep—it'll fall in the back of the boat. (Pause) Because, the ball is falling straight down but the boat is moving
Jessica: (Interrupting) the boat is moving, which exerts a force on to the ball which makes it go back.
Alison: No it doesn't!
Jessica: Yes it does!
Alison: It's not exerting a force on the ball, it's just moving so that by the time the ball hits it, it's moved over. Yes?
Jessica: No!
Alison: Yes! Because if it exerted a force on the ball it would go that way...
Jessica: No but if it hits at a speed, it goes... (She uses her hands to demonstrate her predicted path of the ball)
Alison: What, no. But if the ball just goes like that...
Jessica: You type then because I don't know how I would express it.

Jessica struggles to articulate her thoughts at this stage of the conversation. However, she soon overcame this lack of confidence to help negotiate their joint written response:

Alison: OK. Because...
Jessica: That the boat is moving...
Alison: (Paraphrasing) That the boat is moving...
Jessica: (Interrupting) So it will fall...
Alison: (Interrupting) No—so by the time...
Jessica: (Interrupting) it'll be on the left...
Alison: (Interrupting) Yeh—by the time...
Jessica: (Interrupting) The time it reaches—yeh—I get you!
Alison: By the time the ball reaches the boat, the boat will have...
Jessica: (Interrupting) Will have moved!
Alison: Will have moved along. (i.e., in a forward direction) Yeh—that makes sense!
(Pause)
Jessica: Yes, it does!

The paraphrasing evident in the discussion here showed active listening by both participants as they constructed their views. The students also frequently interrupted each other as they progressively built on each other's previous statements.

Dave and Pat collaborated in a similar fashion when they tried to predict the outcome of task 10 (Heavy Cup and Ball). In this task, students considered a moving person who releases an object from her hand at the moment she is directly above a cup lying on the ground. In the following extract each person obviously listened attentively to his partner. This attentive listening and collaboration was most obvious in the last few sentences when the students continued to elaborate on the previous speaker's thoughts:

Pat: If she lets it go at X then while she's walking, it should land at C. (In front of the cup)
Dave: Yeh.
Pat: It won't land in the cup because...the ball continues to move forward.
Dave: Like Kinetic Energy or something?
Pat: Yeh—she's applying a force to it as she's walking.
Dave: Yeh—because she's walking, it'll go at the same speed as her.
Pat: Yeh—the ball is going the same speed she is so it will keep travelling forward.

The technical language of physics was an obstacle for Dave as he tried to articulate his ideas but he and his partner were able to create some shared sense making. Anne and Jane also 'bounced ideas' off each other in the process of formulating a reason for their predicted pathway of the slow ball rolling off a table in task 4.

Anne: Wouldn't it (the ball's trajectory) arch more half way down? I guess it would arch more...It leaves the table. Rolly, polly...

(Anne continues to draw the pathway)

Jane: Or would it dip or would it just go straight down? I don't know what do you think? Like umm...
Anne: Yeh.
Jane: It'll just like roll a bit.

(Jane performs a mini-experiment here by rolling a pencil slowly off the table and observing the outcome)

Anne: Sort of like out a bit.
Jane: OK not as much as that but—OK well um—so the ball initially arches slightly away from the table then just drops? (Looking for support)
Anne: Yeh, the ball's motion is still going this way but due to gravity it's dropping. It

doesn't land straight down because it's got (forward) motion.
Jane: Yeh, as the ball's motion is still moving away from the table but gravity is pulling it towards the ground.

(Jane rolls the pencil off the table again and considers her observations)

As one student articulated a response, her partner immediately built on this statement in the next comment. Both students began this dialogue in a tentative manner but increasingly gave each other confidence to formulate a detailed reason. This had the overall effect of the two students co-constructing a mutual reason for their prediction.

A few groups met the challenge of reconsidering their views in the explanation stage of the POE strategy (see section 6.3). Cath and Michelle progressed 'one step further' and tried to negotiate an explanation for their incorrect prediction after viewing the video of the slow ball rolling off a table in task 4. After a careful comparison between the drawing of their predicted pathway and their video observations, they made a collaborative attempt to explain the observed path of the ball. (They actually attempted this verbal explanation straight after viewing the video clip.)

Michelle: Play it fast first and then I can do it slowly.
Cath: Do you think our (prediction) was a bit more steep than that?
Michelle: Yeh.
Cath: Or not. I think ours was a bit too steep.
(Pause)
Michelle: Do you think it was more like that? (Drawing picture)
Cath: Do you think?
Michelle: Because it wasn't nowhere near that steep.
Cath: Yeh, OK. Do you want to check (with the video) one more time just to make sure?
Michelle: Yeh—it (the ball's pathway) was steeper. That's right.
Cath: That's the bit that's different. (Pointing to drawing) How can we say it differently to what we predicted? (Starts writing the response) It seems to fall steeper at the bottom than it does at the top.
Michelle: It falls in a curve; it curves; it's projected off the table and goes forward and the gravity force slowly pulls the ball down to the ground.
Cath: (slowly and thoughtfully) It pretty much falls though really.
Michelle: Yeh, but I mean it still comes over here (going forward off the table) and falls towards the ground.
Cath: Do you think? It's almost a line. Although it does curve from the top. Maybe it curves before it falls, I don't know.
Michelle: So it gains velocity and falls faster. (Stated while typing response)

Cath: Yeh.

Like their peers, Cath and Michelle had never formally studied two-dimensional motion and hence these ideas represented an effective attempt to negotiate some meaning of horizontal and vertical components in projectile motion. Cath's comment that the projectile "pretty much falls" (as well as Michelle's following comment) was particularly perceptive as it quite accurately described the vertical component of a projectile's motion!

In summary, there were some incidents of genuine co-construction of knowledge in the peer groups. These discussions often showed characteristics of an 'open discourse' (Taylor et al., 1994), as students actively listened to each other and generated ideas with a mutual respect for each other's point of view.

6.5 Conclusion

This chapter presented the findings relating to Research Question 1: 'To what extent do the computer-mediated POE tasks promote meaningful discussion about students' science ideas?' The POE computer tasks encouraged students to engage in rich discussions with their partners about their preconceptions and hence played a special role in augmenting the learning conversations. Many of these discussions occurred during the prediction and reasoning stage and also after surprising outcomes in the observation stage of the POE tasks. Not surprisingly, more detailed discussions were generally observed during the more challenging tasks, although the use of a drawing format for student responses seemed to enhance discussions in more simple tasks. Both students and teachers perceived these discussions to be valuable learning experiences.

Most students freely articulated their ideas to their partner. Students often disputed their partner's views and this gave them many opportunities to defend and justify their own views, often elaborating on a previously articulated idea. However, a limited science vocabulary sometimes impeded the articulation process, particularly when students attempted to describe or explain the two dimensional nature of projectile motion.

Most students listened carefully to their partner's ideas and there were many instances where students showed strong reflection on the viability of these and their own ideas. Again this mainly occurred during conversations over a disputed prediction and reason or after a surprising outcome. Some students reviewed their experiences from previous tasks and made quite complex and mature comparisons between tasks. One of the features of this reflection was the high incidence of students' non-verbal communicative acts. These included gestures relating to each task as well as collaborative mini-experiments as students considered their responses. The dialogue that accompanied these student initiatives indicated a high level of cognitive engagement and reflection on force and motion concepts.

Incidents of genuine co-construction and negotiation of new or reformulated ideas between group members were less frequent. This could be attributed to various influences ranging from the time constraints placed upon the students as they worked through the POE tasks to the students' limited science vocabulary and consequent lack of confidence to engage in such sense making. However, some groups certainly engaged in this process and their co-construction of new ideas was highly successful.

Students extensively participated in rich and meaningful discussions leading to articulation and reflection on force and motion concepts. The POE computer tasks and associated 'inscriptions' such as the students' drawings served as an effective backdrop to these conversations and a tool for collaborative sense making.

CHAPTER 7
THE STUDENTS' PERSONAL SCIENCE VIEWS ELICITED THROUGH THEIR ENGAGEMENT WITH THE PROGRAM

7.0 Overview of chapter

This chapter focuses on the students' science views elicited through their collaborative engagement with the program. Hence, this section of the study deals with the use of the computer-mediated POE tasks as an instrument to elicit students' science ideas. Teacher perceptions are discussed followed by a comprehensive description of the students' alternative conceptions elicited through their interaction with the computer-mediated POE tasks. The consistency of these views with the science education literature also is addressed. The main research question relevant to this chapter is given below, along with three subsidiary research questions:

Research Question 2:
Does the students' engagement with the program effectively elicit their personal science views?

Subsidiary questions:
I. Do the teachers perceive the program to be a useful probe of students' science views?
II. To what extent do the students reveal any alternative conceptions?
III. What are the students' alternative conceptions and are they consistent with the science education literature?

Discussion directed by these research questions is based around two general assertions. The first assertion relates to both subsidiary questions I and II while the second assertion relates to subsidiary question III. The assertions are supported by data from students' written responses and drawings, teacher surveys and interviews. Audio recordings of student conversations were not used as a data source in this section for two reasons. Firstly, there was sufficient data from other sources to comprehensively address the research questions relevant to this section. Secondly, under normal teaching conditions, teachers using instruments to investigate students' understanding do not have time to record and analyse students' conversations. Hence, this source of data was excluded to reflect these typical teaching conditions.

7.1 Assertion 1: Both teachers perceived the program to be an efficient and effective way to elicit students' science views. A rich variety of alternative conceptions were revealed from the students' interaction with the program.

Teacher survey and interview data showed that both teachers perceived the POE computer tasks to be a valuable instrument for investigating their students' pre-instructional conceptions. Judy particularly found that her observations of students' conversations and drawings during the computer sessions were a helpful supplement to the students' text responses recorded on the computer. Data from the students' written responses and drawings revealed an interesting variety of personal science views, indicating that the POE tasks had indeed effectively elicited students' science conceptions.

7.1.1 Teacher perceptions

Both teachers believed the predict–observe–explain computer tasks were an appropriate instrument to probe students' science views. Judy in particular had used a wide range of diagnostic instruments in her physics class but remained impressed with the rich variety of students' views elicited by these computer-mediated tasks (e.g., refer to items 4 and 37 in Table 7.1). She made the following (completely optional) comment in her survey completed immediately after the computer sessions: "My observations of their conversations and drawings gave me a good understanding of their views." This

Table 7.1
Teachers' responses to items relating to the program's effectiveness as a probe of understanding from the survey: Reflections on the POE Computer Tasks (n=2)

Survey Item	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
4. The program is an inefficient way of probing students' personal science ideas.	Judy	Wayne			
10. I would prefer to use other techniques (e.g., student interviews, group reports etc.) to find out students' ideas.		Judy Wayne			
37. The program effectively elicited students' own personal views.				Wayne	Judy
47. I discovered some common alternative conceptions through my conversations with different groups as they used the program.			Wayne	Judy	
56. The computer printout of the students' responses is a useful record of their ideas.				Judy Wayne	

comment was made before she had read the students' recorded text responses and hence was mindful of her interactions with the students during these sessions (see item 47). She also made the following comment when asked about the usefulness of the tasks in this assessment context: "Very useful. It gives me absolutely an idea in how far back I have to go in 'tackling' acceleration due to gravity etc." In relation to item 10, both teachers mentioned in their interview that in general they would still prefer to use a variety of instruments to investigate their students' conceptions in their classes. (For example, Judy mentioned that she also uses written tests.) Wayne had some reservations about the efficiency of the elicitation process in relation to the timetable and curriculum constraints but spoke positively about the educational value of the instrument during his interview:

> Well it's not efficient in terms of the way science education is sort of constrained in this state and I would dare say throughout Australia, because ... there's the constraints of timetables and assessment, both school-based and external assessment—the HSC whatever—a certain amount of work to get through—the competition ranking procedures, and all the rest of it ... but I think it [the computer program] allows excellent science education to occur, if that's what we are primarily about. (From teacher interview with Wayne)

Wayne made similar pragmatic comments during the course of the study—his concern about curriculum constraints was important and also was mentioned in section 5.9.3. However, he did appreciate other benefits of using video-based demonstrations in terms of classroom efficiency. The saving of demonstration preparation (and implementation) time was significant for him:

> It's going to work, number one. For example, to set up something like the hose [task 16]—which I thought there was an awful lot of stuff in that... a lot of stuff that you could progress towards—it's there in front of you, you don't have to take everyone out and bring everyone back. (From teacher interview with Wayne)

In summary, both teachers believed the computer tasks effectively facilitated the elicitation of students' science conceptions. They indicated that the tasks were efficient in relation to other diagnostic instruments, although Wayne had some concerns about fitting this type of activity into an already crowded teaching program.

7.1.2 Extent of elicitation of students' alternative conceptions

Data from the students' written responses and drawings revealed a large variety of interesting personal science views. Many students displayed an impressive understanding of physics concepts considering their minimal formal instruction in mechanics. However, there were almost 300 incidents where students' views were contrary to the established science view (refer to Tables 7.2 and 7.3). Most of these incidents were related to mechanics, 66% involving some form of naive impetus theory. A few incidents (mainly from task 9) were related to astronomy. Most groups provided more than 10 incidents where they revealed a major alternative conception and most tasks elicited more than 20 alternative conceptions (over both classes). Most incidents occurred in the prediction and reasoning stage, although approximately 10 incidents occurred where alternative conceptions were identified in the observation stage.

Students generally recorded thoughtful and imaginative reasons for their predictions that often provided a window into their pre-Newtonian world. The six drawing tasks provided students with a non-textual mode for expressing their ideas, and these drawings were rich in detail and became a valuable source of data for analysing and identifying the students' preconceptions (see Assertion 7.2).

7.1.3 Summary

Teachers perceived the POE computer tasks to be a useful instrument to probe students' understanding. Many alternative conceptions were elicited through the students' interaction with the program, indicating that the tasks were indeed effective in eliciting students' personal science views.

Assertion 7.2: Common pre-Newtonian conceptions were prevalent amongst students from both classes. Students' alternative conceptions were consistent with the literature.

Students' drawings and written responses revealed an interesting variety of impetus related views as well as some Aristotelian beliefs. These views were consistent with the literature. The following discussion will report on these views elicited from the students' engagement with the POE tasks depicting vertical motion, the tasks depicting projectiles launched passively from moving carriers and finally, the tasks depicting actively launched projectiles.

7.2.1 Discussion of alternative conceptions elicited through the students' engagement with tasks depicting vertical motion

Few students had problems with tasks 1 (Falling Ball) or task 2 (Rising Ball). Most

Table 7.2

Incidents elicited from written responses and drawings where students' views were contrary to science view (Class 1. N= 9 groups)

Key:

●	Response contrary to science view	●^{I}	Response related to impetus theory
●^{c}	Circular impetus belief	●^{A}	Response related to Aristotelian theory
●^{g1}	Gravity changes dramatically with height near Earth's surface over one metre.		
●^{g2}	Gravity linked to air pressure	●^{g3}	No gravity on moon

Group	Phase	Task 1 Falling Ball	Task 2 Rising Ball	Task 3 Ball Launch	Task 4 Slow Ball Roll	Task 5 Fast Ball Roll	Task 6 Car Launch	Task 7 Soccer Ball	Task 8 Boy & Swing	Task 9 The Moon	Task 10 Light Ball & Cup	Task 11 Heavy Ball & Cup	Task 12 Sailing Boat	Task 13 Two Balls Falling	Task 14 Cart & Ball 1	Task 15 Cart & Ball II	Task 16 The Hose	*SUB -TOT*	*TOT*
1	*Pred.*			●		●^{I}	●^{I}			●^{A}			●^{I}	●	●^{I}	●	●	9	
Jilly &	*Reason*				●^{I}	●^{I}	●^{I}			●^{A}			●^{I}	●^{I}			●^{g1}	7	
Rochelle	*Obsv.*						●	●										2	
	Expl.																●	1	19
2	*Pred.*								●^{c}				●^{I}	●	●^{I}	●	●	6	
Jane &	*Reason*				●^{I}			●^{I}	●^{c}	●^{g2}			●^{I}	●				6	
Anne	*Obsv.*								●									1	
	Expl.																	0	13
3	*Pred.*					●^{I}			●^{I}				●^{I}	●	●^{I}	●		6	
Belinda &	*Reason*	●^{g1}				●^{I}		●^{I}	●^{I}	${}_{3}$●			●^{I}	●^{I}				7	
Joanna &	*Obsv.*																	0	
Melissa	*Expl.*			●^{I}														1	14
4	*Pred.*						●^{I}			●^{A}	●^{I}	●^{I}		●		●		6	
Cath &	*Reason*			●^{I}		●^{I}	●^{I}			●^{A}	●^{I}	●^{I}					●^{I}	7	
Michelle	*Obsv.*																	0	
	Expl.										●^{I}					●^{I}		2	15

Table 7.2 (continued)

Incidents elicited from written responses and drawings where students' views were contrary to science view (Class 1. N= 9 groups)

Group	Phase	Task 1 Falling Ball	Task 2 Rising Ball	Task 3 Ball Launch	Task 4 Slow Ball Roll	Task 5 Fast Ball Roll	Task 6 Car Launch	Task 7 Soccer Ball	Task 8 Boy & Swing	Task 9 The Moon	Task 10 Light Ball & Cup	Task 11 Heavy Ball & Cup	Task 12 Sailing Boat	Task 13 Two Balls Falling	Task 14 Cart & Ball I	Task 15 Cart & Ball II	Task 16 The Hose	*SUB -TOT*	*TOT*
5	*Pred.*				$\bullet^{I}$	$\bullet^{I}$	●		$\bullet^{I}$				●	●	$\bullet^{I}$		●	8	
Clare &	*Reason*					$\bullet^{I}$	$\bullet^{I}$		$\bullet^{I}$	$\bullet^{g3}$			$\bullet^{I}$					5	
Evelyn	*Obsv.*																	0	
	Expl.																	0	13
6	*Pred.*						$\bullet^{I}$		$\bullet^{I}$	●	$\bullet^{I}$	$\bullet^{I}$	$\bullet^{I}$	●	$\bullet^{I}$	●		9	
Louise &	*Reason*		$\bullet^{A}$	$\bullet^{I}$		$\bullet^{I}$	$\bullet^{I}$		$\bullet^{I}$			$\bullet^{I}$						6	
Nerida	*Obsv.*																	0	
	Expl.									●								1	16
7	*Pred.*						●				$\bullet^{I}$		$\bullet^{I}$					3	
Alison &	*Reason*				$\bullet^{I}$		$\bullet^{I}$	$\bullet^{I}$	$\bullet^{I}$		$\bullet^{I}$		$\bullet^{I}$	$\bullet^{I}$	$\bullet^{I}$	$\bullet^{I}$		9	
Jessica	*Obsv.*					$\bullet^{I}$	$\bullet^{I}$											2	
	Expl.					$\bullet^{I}$					$\bullet^{I}$							2	16
8	*Pred.*				●		$\bullet^{I}$			$\bullet^{A}$		$\bullet^{I}$	$\bullet^{I}$	●		●	●	8	
Joan &	*Reason*	$\bullet^{I}$			$\bullet^{I}$	$\bullet^{I}$	$\bullet^{I}$		$\bullet^{I}$	$\bullet^{A}$		$\bullet^{I}$	$\bullet^{I}$	$\bullet^{I}$	$\bullet^{I}$	$\bullet^{I}$		11	
Leigh	*Obsv.*																	0	
	Expl.									$\bullet^{g2}$	$\bullet^{I}$	$\bullet^{I}$	$\bullet^{I}$			●		5	24
9	*Pred.*					$\bullet^{I}$	$\bullet^{I}$	$\bullet^{I}$	●				$\bullet^{I}$	●	$\bullet^{I}$		●	8	
Jenny &	*Reason*					$\bullet^{I}$	$\bullet^{I}$	$\bullet^{I}$	$\bullet^{I}$				$\bullet^{I}$	$\bullet^{I}$				6	
Kirstie	*Obsv.*																	0	
	Expl.					$\bullet^{I}$												1	15
	TOT	2	1	4	6	14	16	6	13	12	8	7	16	14	8	10	8	**145**	

Table 7.3

Incidents elicited from written responses and drawings where students' views were contrary to science view (Class 2. N=13 groups)

Key:

- • Response contrary to science view
- $\bullet^{I}$ Response related to impetus theory
- $\bullet^{c}$ Circular impetus belief
- $\bullet^{A}$ Response related to Aristotelian theory
- $\bullet^{g1}$ Gravity changes dramatically with height near Earth's surface over one metre
- $\bullet^{g2}$ Gravity linked to air pressure
- $\bullet^{g3}$ No gravity on moon

Group	Phase	Task 1 Falling Ball	Task 2 Rising Ball	Task 3 Ball Launch	Task 4 Slow Ball Roll	Task 5 Fast Ball Roll	Task 6 Car Launch	Task 7 Soccer Ball	Task 8 Boy & Swing	Task 9 The Moon	Task 10 Light Ball & Cup	Task 11 Heavy Ball & Cup	Task 12 Sailing Boat	Task 13 Two Balls Falling	Task 14 Cart & Ball I	Task 15 Cart & Ball II	Task 16 The Hose	*SUB -TOT*	*TOT*
1	*Pred.*				$\bullet^{I}$		$\bullet^{I}$		$\bullet^{I}$				$\bullet^{I}$	•	$\bullet^{I}$			6	
Sam &	*Reason*	•				$\bullet^{I}$	$\bullet^{A}$		$\bullet^{I}$				$\bullet^{I}$					5	
Laurie	*Obsv.*								$\bullet^{I}$			$\bullet^{I}$						2	
	Expl.																	0	13
2	*Pred.*			•	•		•		•				$\bullet^{I}$					5	
Barry &	*Reason*			$\bullet^{I}$		$\bullet^{I}$		$\bullet^{I}$	$\bullet^{I}$				$\bullet^{I}$					5	
Carl	*Obsv.*																	0	
	Expl.																	0	10
3	*Pred.*			•						$\bullet^{A}$		$\bullet^{I}$		•			•	5	
Brett &	*Reason*						$\bullet^{I}$			•		$\bullet^{I}$						3	
Nick	*Obsv.*																	0	
	Expl.																	0	8
4	*Pred.*						•							•				2	
Henry &	*Reason*						$\bullet^{I}$		$\bullet^{I}$	$\bullet^{g3}$								3	
Alan	*Obsv.*					$\bullet^{I}$												1	
	Expl.																	0	6
5	*Pred.*				•									•				2	
Pat &	*Reason*				$\bullet^{I}$													1	
Dave	*Obsv.*																	0	
	Expl.																	0	3
6	*Pred.*									$\bullet^{A}$		$\bullet^{I}$			$\bullet^{I}$			3	
Ted &	*Reason*				$\bullet^{I}$					$\bullet^{A}$		$\bullet^{I}$						3	
Claude	*Obsv.*																	0	
	Expl.																	0	6

Table 7.3 (continued)

Incidents elicited from written responses and drawings where students' views were contrary to science view (Class 2. N=13 groups)

Group	Phase	Task 1 Falling Ball	Task 2 Rising Ball	Task 3 Ball Launch	Task 4 Slow Ball Roll	Task 5 Fast Ball Roll	Task 6 Car Launch	Task 7 Soccer Ball	Task 8 Boy & Swing	Task 9 The Moon	Task 10 Light Ball & Cup	Task 11 Heavy Ball & Cup	Task 12 Sailing Boat	Task 13 Two Balls Falling	Task 14 Cart & Ball I	Task 15 Cart & Ball II	Task 16 The Hose	*SUB -TOT*	*TOT*
7	*Pred.*				●^{I}	●^{I}							●^{I}	●	●^{I}	●		6	
Rory &	*Reason*					●^{I}				●^{g3}		●^{I}						3	
Simon	*Obsv.*																	0	9
	Expl.																	0	
8	*Pred.*			●^{I}		●^{I}	●^{I}		●				●^{I}		●^{I}	●		7	
Wally &	*Reason*			●^{I}	●^{I}	●^{I}	●^{I}	●^{I}	●^{I}	●^{g3}								7	
Barney	*Obsv.*																	0	14
	Expl.																	0	
9	*Pred.*												●^{I}	●		●		3	
Mick &	*Reason*			●^{I}	●^{I}	●^{I}	●^{I}			●^{g3}								5	
Pierre	*Obsv.*																	0	8
	Expl.																	0	
10	*Pred.*											●^{I}			●^{I}	●		3	
Tom &	*Reason*			●			●^{I}					●^{A}						3	
Toby	*Obsv.*																	0	6
	Expl.																	0	
11	*Pred.*				●^{I}		●^{c}			●^{A}		●^{I}		●		●		6	
Tony & Roger	*Reason*				●^{I}			●^{I}		●^{A}		●^{I}		●^{I}				5	
	Obsv.																	0	12
	Expl.									●^{g3}								1	
12	*Pred.*			●^{I}	●^{I}	●^{I}	●	●^{I}	●^{I}		●^{I}	●^{I}	●^{I}	●				10	
Jack &	*Reason*			●^{I}	●^{I}	●^{I}	●^{I}	●^{I}	●^{I}	●^{g2}	●^{I}	●^{I}	●^{I}					10	
Bill	*Obsv.*						●^{I}											1	21
	Expl.																	0	
13	*Pred.*	●								●^{A}	●^{I}		●^{I}	●		●		6	
Bob &	*Reason*				●^{I}	●^{I}				●^{A}	●^{I}	●^{I}			●^{I}	●^{I}		7	
Rick	*Obsv.*																	0	
	Expl.										●^{I}		●^{I}					2	15
	TOTAL	2	0	9	13	11	14	5	10	14	5	13	11	10	6	7	1	**131**	

students realised that the ball moves faster as it falls and slows down as it rises. However, analysis of students' reasons found that some students had alternative conceptions of gravity near the surface of the earth. The Aristotelian belief that heavy objects fall faster than light objects (Gunstone & White, 1981) was a common alternative conception emerging from task 9.

Students' responses to tasks 1 and 2. Many students from both classes misused the term *acceleration* in tasks 1 and 2. Misuse of this term has been well reported in the literature (e.g., Whitaker, 1983). Simon and Rory could not differentiate between the terms *speed* and *acceleration*, stating: "We think that the ball will get faster as the acceleration speed is 9.8 m\s\s and the ball will take longer than a second to hit the floor." Similarly, Jessica and Alison confused increasing speed and increasing acceleration: "The ball will get faster because the acceleration will increase because of the gravity that pulls the ball closer to the ground." The confusion of these quantities was well documented by Jones (1983).

Bob and Rick displayed Aristotelian beliefs as they predicted that the ball would travel at constant speed as it fell over a distance of approximately one metre (in task 1): "The ball will travel at a constant speed because the mass and the weight of the ball stays the same and also gravity stays the same." This again is a well-documented common alternative conception amongst students (Champagne et al., 1980). Alternatively, Sam and Laurie predicted that the ball would increase its speed as it fell but then reasoned that the ball would reach terminal speed after a while: "[The ball will increase its speed] because of the pull of gravity on the ball pulling on it until it reaches terminal velocity."

Belinda, Joanna and Melissa made a correct prediction in task 1 but their reasoning also was contrary to the accepted science view. They predicted that the ball would increase its speed as it fell but reasoned that this was because gravity increases noticeably on the way down: "The ball will fall at a faster rate because the gravity increases as the ball falls down." Indeed, a number of students firmly believed that the strength of the earth's gravity changes significantly over a small distance above the earth's surface. This alternative conception is extensively reported in the literature (e.g., Champagne et al., 1980; Driver et al., 1994; Gunstone & White, 1981).

Task 2 was a simple but well considered task in the literature (e.g., Clement, 1982). Many responses in this task had strong impetus connotations, implying that the ball carried an 'internal force' after being launched vertically upwards. For example, Belinda, Joanna and Melissa believed the ball rises upwards because the thrower imparted such a 'force' on the ball: "The ball will go up because the little girl applies a force onto it forcing it to go up. After it reaches its maximum height it will then fall down again due to gravity." Nerida and Louise expressed a contrary science view that seemed to be a strange mix of Aristotelian and impetus ideas; this common phenomenon is reported in Viennot, (1979) and Halloun and Hestenes (1985a). These girls made a correct prediction but their reasoning was flawed: "[The ball will slow down] because the air pressure under the ball is increasing and the energy of throwing the ball decreases." These students adopted an Aristotelian view as they considered external forces (changing air pressure under the ball) responsible for the ball's motion. They then discussed the diminishing energy in the ball, implying a more internal impetus property.

Students' responses to task 9. Task 9 was unique in that it was the only task showing a demonstration from outside the earth's gravitational field. It involved an astronaut on the moon dropping a hammer and a feather at the same time. There were many alternative views elicited from this task (see Figure 7.1). As expected, many students demonstrated

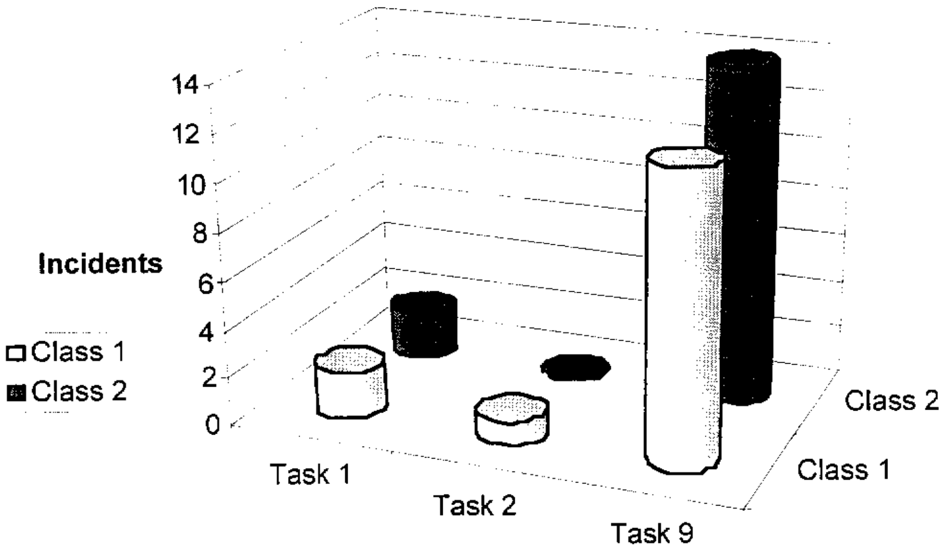


Figure 7.1. Incidents where students' views were contrary to the correct science view: vertical motion tasks.

the belief that heavy objects fall faster than light objects (Gunstone & White, 1981). The following reasons were typical responses of students who predicted the hammer to hit the surface of the moon before the feather. Bob and Rick reasoned: "Because the hammer is heavier than the feather even at a lower gravity." Rochelle and Jilly gave a similar explanation: "Even though there is less gravity on the moon, there is still some, and the heavier object would still hit the ground first." Although it was acknowledged that the moon has a lower gravity than earth, these students still held the view that heavy objects fall faster.

A major alternative conception in class 2 was the belief that there was no gravity on the moon (refer to Table 7.3). This alternative conception is reported in many studies from the literature (e.g., Driver et al., 1994; Sequeira & Leite, 1991). Despite this alternative conception, many of these groups predicted that the objects would fall and indeed hit the ground at the same time! Three groups from both classes held the common belief that gravity was somehow related to air pressure or the presence of an atmosphere. (See also for example, Driver et al., 1994; Gunstone & White, 1981). Joan and Leigh seemed to associate gravity with the presence of air in their task 9 explanation: "We predicted they [the hammer and feather] would fall separately but they fell at the same time. This may be because the gravity is so minimal it is as though the objects are falling in a vacuum." The confusion in this task was a major concern for Wayne (the teacher of class 2) and he chose to focus on the nature of gravity in his follow-up lesson.

7.2.2 Discussion of alternative conceptions elicited through the students' engagement with tasks depicting projectiles released passively from carriers

Projectiles launched passively from moving carriers have proven to be real problems for students holding strong impetus beliefs (Fischbein et al., 1989; McCloskey et al., 1983; Millar & Kragh, 1994). The classic impetus reasoning to these types of problems (e.g., a plane dropping a bomb) is that the carrier does not impart any impetus on to the object and hence falls straight down—following a vertical path (or blown backwards). Similar alternative conceptions were elicited from students in this study through their interactions with these four POE tasks (Ball and Swing, Heavy Ball and Cup, Light Ball and Cup and The Sailing Boat).

Student responses to task 8. The drawings of Clare and Evelyn (see Figure 7.2), as well as Belinda, Joanna and Melissa (see Figure 7.3), were typical of many impetus related predictions in task 8 (Ball and Swing). In this task, a boy is still travelling upwards on a swing when he releases a ball. As the ball was not actively launched, Belinda, Joanna and Melissa believed that the ball would be dominated by gravity and fall vertically downward in a straight line. They noted in their reasoning that: "The ball will go straight down because there is no force applied and gravity will make it fall straight down." Indeed, their observation of the ball in this task (see dotted line) was inaccurate—a feature of many incidents discussed in this chapter. These incorrect observations are often a direct influence of students' strongly held personal beliefs (White & Gunstone, 1992). Jack and Bill made a similar prediction (see Figure 7.4) and in their reasoning used the term *momentum* to infer the impetus of the projectile: "The ball does go straight down because there is no sideways momentum." The use of

Figure 7.2. Clare and Evelyn's prediction (continuous line) and observation (dotted line) in task 8 (Ball and Swing).

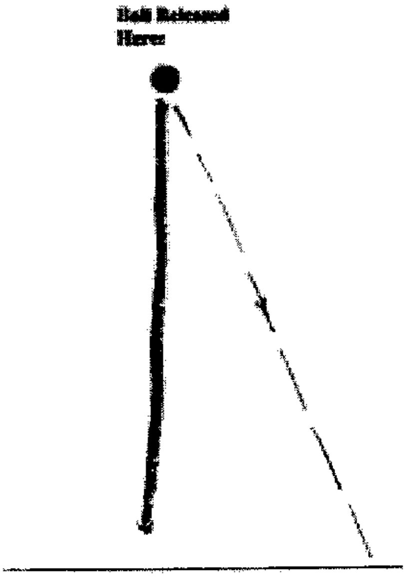


Figure 7.3. Belinda, Joanna and Melissa's prediction (continuous line) and observation (dotted line) in task 8.

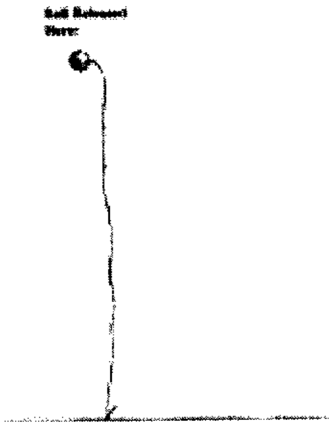


Figure 7.4. Jack and Bill's prediction (continuous line) and observation (dotted line) in task 8 (Ball and Swing).

the term *sideways* is interesting here. A number of groups used similar terms to imply a consideration of the horizontal component of a projectile's motion. Mindful of these students' lack of formal physics instruction, this was a major intellectual step for these students! Indeed, in the context of the history of science, it was not until Galileo in the 16th century that projectile motion was analysed using horizontal and vertical components (Crombie, 1959)! Nerida and Louise had a strong concern for the air blowing in the opposite direction to the motion of the ball after it was released in the same task. Their drawn prediction (see Figure 7.5) for task 8 was supported by the following reason: "It is because the air pressure at the right hand side of the picture of the ball increases, so the ball is forced to drop at the left hand side of the picture." The effect of air has been a common concern of students in many studies (Halloun & Hestenes, 1985a). Indeed, Millar and Kragh (1992) labelled this same belief the 'reverse velocity' theory.

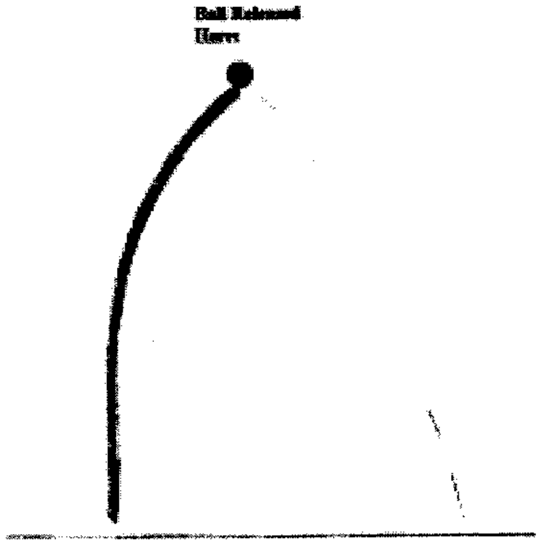


Figure 7.5. Nerida and Louise's prediction (continuous line) and observation (dotted line) in task 8 (Ball and Swing).

A circular impetus belief emerged in Jane and Anne's task 8 responses. They did not fully understand the question, thinking that the boy on the swing was on his way down rather than up. Nevertheless they still predicted that the ball would retain some of its circular motion properties after it was released (see Figure 7.6). Their reasoning also implied a circular impetus belief: "The ball arches away from the release point due to circular motion and gravitational pull." It also was interesting to note that their observed pathway seemed to be strongly influenced by their circular impetus views—their observed pathway was drawn concave up!

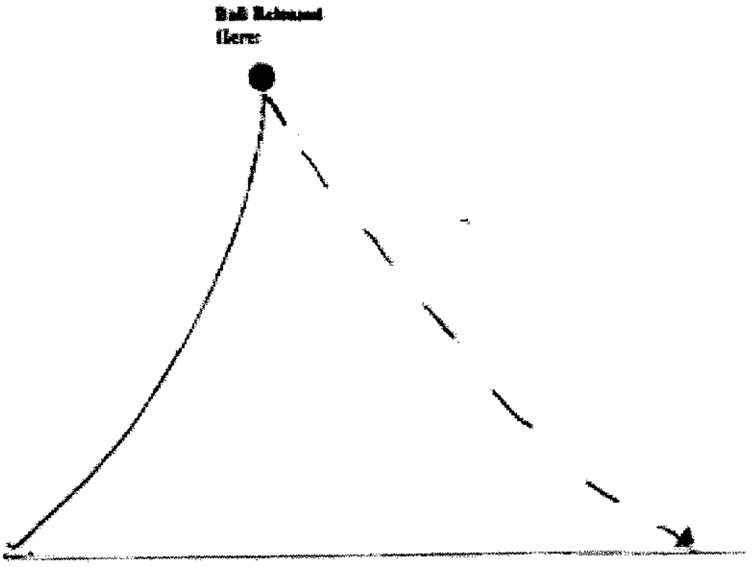


Figure 7.6. Jane and Anne's prediction (continuous line) and observation (dotted line) in task 8 (Ball and Swing).

Students' responses to tasks 10 and 11. Cath and Michelle gave a classic impetus view in their reasoning for task 10 (Heavy Ball and Cup). They were concerned about the lack of any internal force to move the ball beyond the cup (after the person walking released the ball directly above the cup). Hence, they predicted the ball would fall directly into the cup for the following reason: "The heavy ball will fall straight down [into the cup] as there is no force behind the ball projecting it left to right." After observing the ball travel beyond the cup in the task 10 video demonstration, Cath and Michelle were still concerned about the heaviness of the ball as they gave their reason for the (lighter) ball falling into the cup in the following task number 11 (Light Ball and Cup): "[The light ball will fall in the cup] because the object is so light it will not carry the force of movement forward and so will fall straight down." Like many impetus theorists, they linked the object's lack of heaviness with its internal force of movement or impetus! Bob and Rick also decided to attribute the ball's forward motion to a 'motion implies a force' theory. After predicting that the ball would land in the cup in task 10, they observed the outcome before explaining: "Yes [our prediction was different to out observation], because the ball contains the forward motion force." This confusion between force and impetus was common amongst students from both classes. Students from many other studies have displayed the similar alternative conceptions (e.g., Fischbein et al., 1989; Halloun & Hestenes, 1985a; McDermott, 1984).

Students from both classes often misused the terms *momentum* and *energy* to disguise their impetus beliefs. (This confusion of terms is reported in McCloskey, 1983a; McDermott, 1984; and Whitaker, 1983.) Wayne particularly noticed the misuse of the word *momentum* amongst his male students and attributed this phenomenon to the students' exposure to this word in a context—particularly football commentary on television. The following extract was taken from the Year 10 field notes:

> Immediately after the computer sessions, Wayne and I discussed the students' noticeable use of the word *momentum* in many tasks. He attributed it to the students' exposure to this word in a sporting commentary context—in particular football contexts. He used the following football cliché as an example of the use of this word when a player scores a 'try': 'his *momentum* carried him over the line!'

Indeed, *momentum* is an inviting term for impetus theorists as it embodies the two properties that are usually associated with impetus theory: heaviness and speed. Like Jack and Bill's responses to task 8, Joan and Leigh disguised their impetus beliefs through their misuse of this word. In task 11 (Heavy Ball and Cup), they reasoned that: "[The ball will land in the cup] because it is not heavy enough to have a strong enough momentum to carry it [the ball] over the cup." Mass was a large concern for Ted and Claude who confused impetus ideas with the term *energy*. They predicted that the ball would land in the cup in task 11 because "paper has less mass and therefore stores less energy."

Students' responses to task 12. Task 12 (Sailing Boat) was the biggest problem for most students (see Figure. 7.7) in these tasks depicting passive launches from carriers. Although the physics involved in this task is actually similar to the preceding two

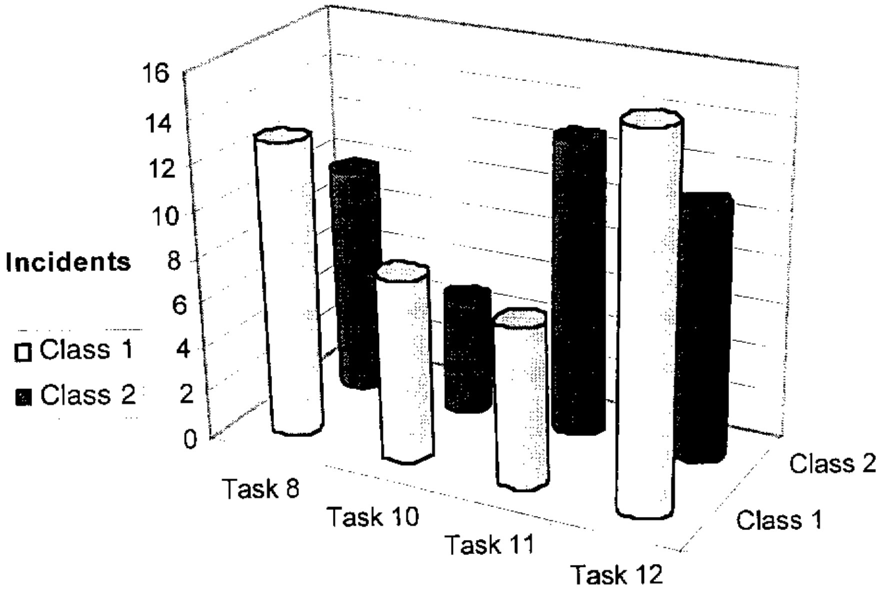


Figure 7.7 Incidents where students' views were contrary to the correct science view in tasks depicting passively launched projectiles.

tasks (a projectile dropped passively from a moving carrier), many students did not see a connection here. Most students predicted that the ball will get left behind by the boat and land behind the mast and many students revealed impetus related views to explain their predictions (as in the Whitaker (1983) study). Alison and Jessica, for example, could not see any reason for the ball to move forward after being released from the mast: "The ball will fall straight down because of the gravity but the boat is moving, so by the time the ball reaches the boat, the boat will have moved along." This reasoning is similar to that used by the figurative Aristotelian character Simplicio in Galileo's *Dialogue Concerning Two Chief World Systems* (1632)—refer to section 3.2.3. Alternatively, Barry and Carl considered the dissipation of impetus, referring to the ball's 'internal momentum' as they gave their reason for predicting the ball to land behind the mast: "...the boat is moving forward but the ball loses its momentum as it falls."

In summary, the tasks depicting projectiles released passively from carriers were a major source of alternative conceptions amongst students in both classes. Most students held the pre-Newtonian view that a moving carrier does not impart any forward motion to a body after it is released. The 'straight down belief' (McCloskey, 1983a), otherwise known as the 'zero velocity' response (Millar & Kragh, 1994), was 'alive and well' in both classes!

7.2.3 Discussion of alternative conceptions elicited through the students' engagement with tasks depicting projectiles launched actively

Five of the six drawing tasks depicted projectiles launched actively. Although seemingly simple tasks (e.g., a person throwing a ball; balls rolling off tables etc.), many of the students' drawings were rich in detail and revealed numerous alternative conceptions. Tasks 4, 5 and 6 were different versions of the cliff problem used in previous studies (e.g., Eckstein et al., 1997; McCloskey, 1983a). The Aristotelian law of support belief was only prevalent amongst a few groups—most students believing that a projectile travels forward after it is launched. However, there were many impetus related written responses and drawings in these tasks, consistent with the literature for students of this age (e.g., Fischbein et al., 1989). The large mass and speed off the car in task 6 (Car Launch) seemed to be particularly inviting for students to express impetus beliefs.

Students' responses to tasks 4 and 5. The context of a slow and fast ball rolling off a table in tasks 4 and 5 elicited some interesting responses with some obvious parallels with 14th century impetus theorists (refer to section 3.2.2). For example, Rory and Simon's task 4 and 5 drawings (see Figures 7.8 and 7.9) depicted Albert de Saxony's classic three-stage projectile theory (Crombie, 1959). This theory predicts that a projectile will travel horizontally for a time before gravity starts to take over from the ball's internal impetus, causing it to curve downward. Finally the ball's impetus diminishes to zero and gravity dominates, giving the ball its vertical pathway. Rory and Simon's reasons were strongly influenced by the ball's speed. For example, their task 5 reasoning showed concern for the critical level when the gravitational force starts to influence the projectile: "As there is more velocity behind the ball, the gravitational force will take longer to 'kick-in'!" Jack and Bill made similar predictions and continued to use the term *momentum* to express their impetus beliefs. The speed of the ball in task 5 was a crucial factor for these 'impetus students'! However, according to their prediction in task 4 (see Figure 7.10), the sideways momentum (or impetus) of the ball eventually diminished and gravity dominated: "As a result of the ball travelling slowly it has little forward momentum and thus gravity will pull it down with little sideways length." The ball is going faster in task 5 (see Figure 7.11), so

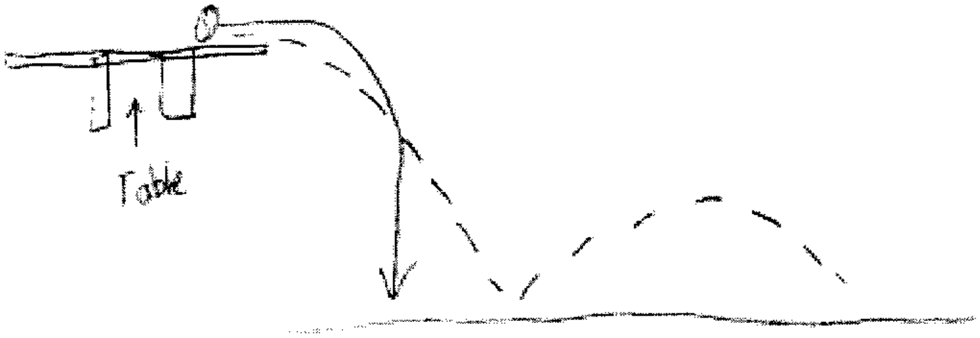


Figure 7.8. Rory and Simon's prediction (continuous line) and observation (dotted line) in task 4 (Slow Ball Roll—off table).

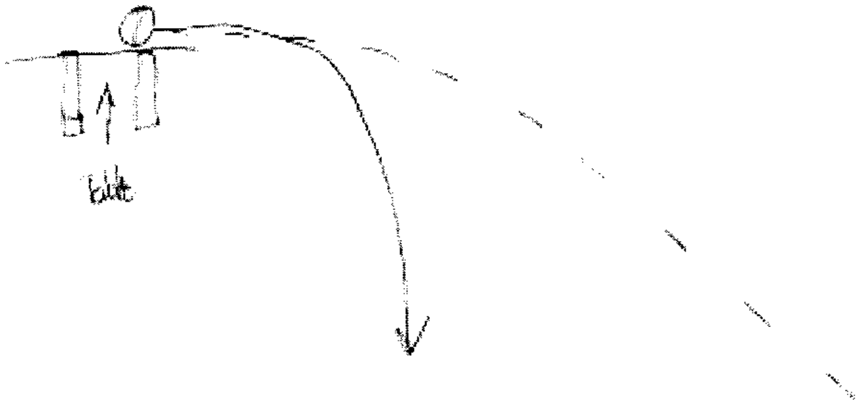


Figure 7.9. Rory and Simon's prediction (continuous line) and observation (dotted line) in task 5 (Fast Ball Roll—off table).

they believed that the ball therefore had more sideways momentum: "...the ball is going fast so it therefore has more sideways momentum."

Figure 7.10. Jack and Bill's prediction (continuous line) and observation (dotted line) in task 4 (Slow Ball Roll—off table).

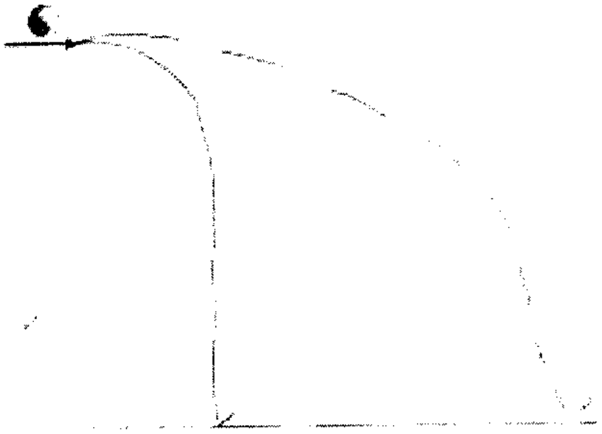


Figure 7.11. Jack and Bill's prediction (continuous line) and observation (dotted line) in task 5 (Fast Ball Roll—off table).

Pat and Dave introduced the term *propulsion* to imply impetus in their task 4 prediction. Interestingly, Pat also uses the term *momentum* again.

Dave:	OK. There's only a little bit of forward propellation [sic], if that's a word.
Pat:	Um...the ball had only a small propulsion (correcting Dave's vocabulary) forward. It didn't have much momentum!

Laurie and Sam also used the term *propulsion* in their task 13 prediction:

Laurie: The ball on the right (will hit first). Do you reckon?
Sam: Yeh—but its going to have propulsion through it... the ball on the left will be travelling faster.
Laurie: It's not being projected downwards, it's being projected across.

The word *through* in Sam's comment again implied an internal impetus property 'propelling' the ball forward!

Nerida and Louise commented on the issue of impetus dissipation during their task 3 reasoning. (In this task a person is throwing a ball horizontally from a small ledge.) As in their task 2 responses, these two girls again used the term *energy* to imply the impetus property, stating that: "The energy when she started throwing was increasing and afterward it started to decrease." For these two students, the gravity eventually dominated the path of the projectile as the ball's impetus diminished. Like many of their peers, Ted and Claude used the term *energy* to imply impetus. This misuse of the term *energy* is reported in other studies (e.g., Fischbein et al., 1989; Twigger et al., 1994). Cath and Michelle commented on the dissipation of a force 'inside' the ball after it had rolled off the table in task 5. They reasoned that: "The force pushing the ball from left to right decreases after the ball has left the surface of the table, it then begins to fall towards the ground, gaining velocity as it falls." Joan and Leigh spoke in similar terms in their task 5 reason but yet again referred to the ball's momentum. They stated that: "Because the ball is going at a faster speed, it will have the ability to be suspended in the air for a longer time period before gradually losing momentum and gravity will force it to the ground."

Kirstie and Jenny decided that when gravity starts to influence a projectile, it falls at a constant angle to the ground. (Halloun and Hestenes (1985a) found similar depictions in their study!) This belief was evident in both their tasks 5 and 6 predictions as shown in Figures 7.12 and 7.13. The speed of the projectiles was a strong influence on their reasoning in this task, recorded on the computer:

> Due to the fast speed of the car before it leaves the cliff, it will continue travelling in its path of direction, without a surface directly below it. The force of gravity will then force the car to fall down the 20m drop at a constant speed at a constant angle to the ground.

According to Jenny and Kirstie, the impetus apparently inside the car took the projectile in a horizontal path before gravity took over at a certain critical level. Interestingly, these students' observation was highly influenced by this preconception, observing the car as travelling horizontally for a (smaller) time before descending (again!) in a straight line at a constant angle to the ground.

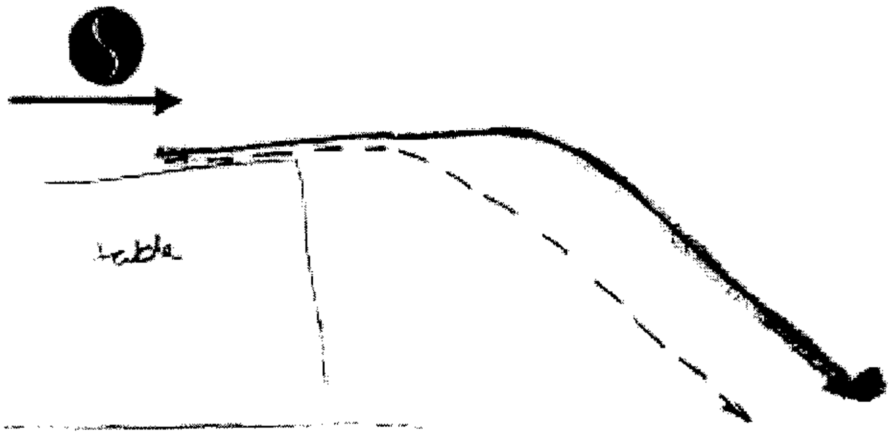


Figure 7.12. Kirstie and Jenny's prediction (continuous line) and observation (dotted line) in task 5 (Fast Ball Roll—off table).

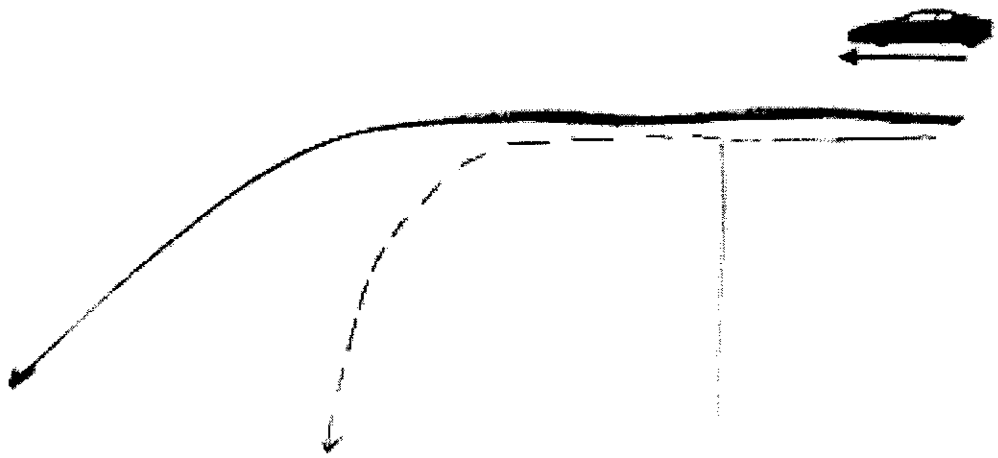


Figure 7.13. Kirstie and Jenny's prediction (continuous line) and observation (dotted line) in task 6 (Car Launch).

Students' responses to task 6. Task 6 proved to be a difficult task for many other students—60% of all students made inaccurate predictions in this task (see Figure 7.14). The combination of a large mass and high speed really invited impetus related views from students in this task. For example, the heaviness of the car was a major reason for Rochelle and Jilly drawing their classic impetus prediction (see Figure 7.15). Indeed, their drawing was reminiscent of Avicenna's 'mail theory' (refer to Figure 3.2a). These girls recorded the following reason for their prediction:

> As it is a heavy car, we predict that the car would fall almost vertically rather than falling at a constant curve, like a ball would. Because it is travelling quite fast, we think that the car would project quite far from the edge of the cliff before falling.

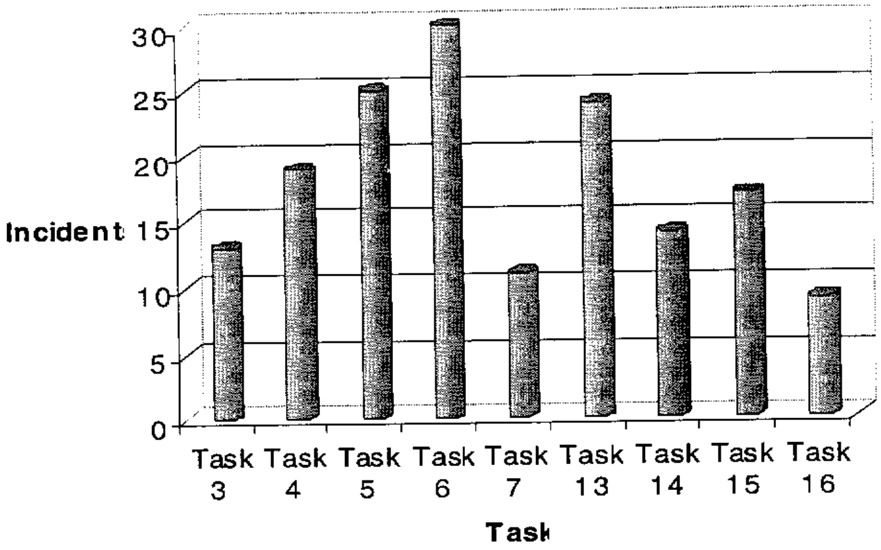


Figure 7.14. Incidents where students' views were contrary to the correct science view in tasks depicting actively launched projectiles.

Unlike most impetus related responses (from both classes), Rochelle and Jilly's task 6 drawing indicated a belief that gravity only takes over when the projectile's impetus has completely dissipated!

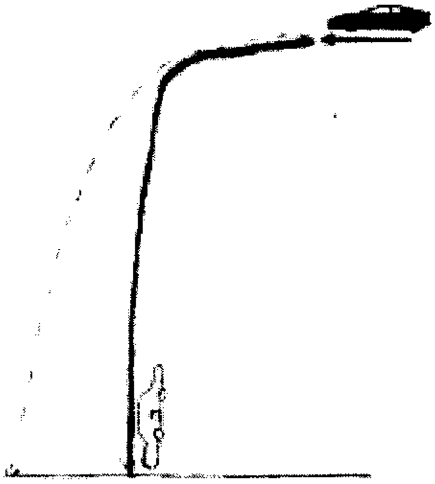


Figure 7.15. Rochelle and Jilly's prediction (continuous line) and observation (dotted line) in task 6 (Car Launch).

Alternatively, Sam and Laurie's drawing for task 6 displayed the Aristotelian belief that as soon as the car loses the support of the cliff, (despite its speed) it will fall almost straight away to the ground due to its heaviness (see Figure 7.16). This was an unusual case as most students predicted the car would at least move forward after losing the 'support' of the cliff. (Indeed, this was in agreement with McCloskey's (1983b) study.) However, Sam's and Laurie's drawn prediction and reason demonstrated a belief in the 'law of support' (Ogborn, 1985) and is similar to the

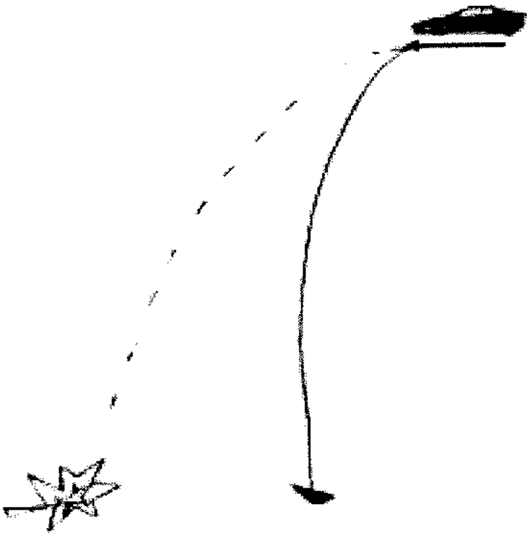


Figure 7.16. Sam and Laurie's prediction (continuous line) and observation (dotted line) in task 6 (Car Launch).

young children's drawings in the Eckstein and Shemish (1993) study. Sam and Laurie reasoned: "Because the car is heavy it will pretty much fall immediately to the ground with the nose impacting first." Tony and Roger displayed a circular impetus belief in their prediction for this same task, as illustrated in Figure 7.17. They believed the

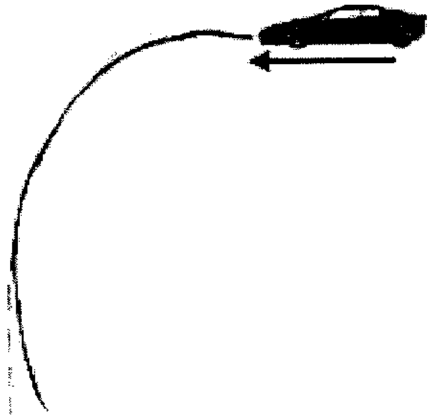


Figure 7.17. Tony and Roger's prediction (continuous line) and observation (dotted line) in task 6 (Car Launch).

rotation of the falling car would affect the pathway of the car's centre of mass! After viewing the video clip, they admitted to this flaw in their explanation, although their observation was still drawn inaccurately! They explained: "There was no real difference apart from the end where it went straight instead of curling in."

Students' responses to tasks 7, 14 and 15. Most students made correct predictions for the path of the (full flight) soccer ball in task 7. Interestingly, Kirstie and Jenny's prediction (and accompanied reason) in this task reflected results from the Halloun and Hestenes (1985a) study and again contained similarities to 14th century theorists. The peak of the flight was critical for these students, as shown in Figure 7.18. According to these students, it was only after the ball reached its maximum height (when the impetus had dissipated) that gravity influenced the ball:

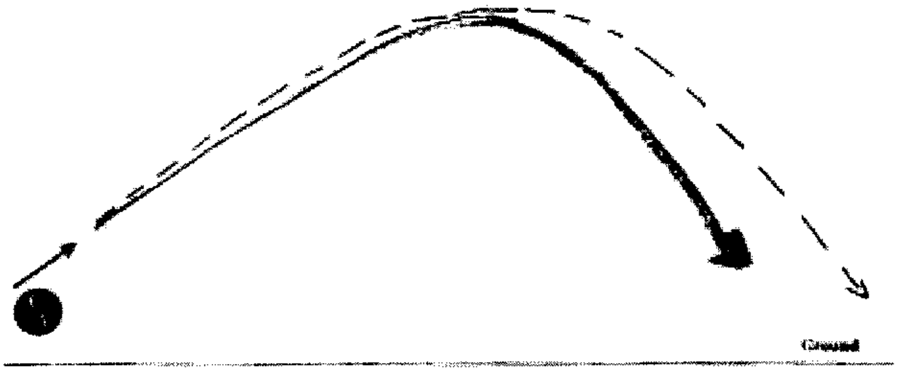


Figure 7.18. Kirstie and Jenny's prediction (continuous line) and observation (dotted line) in task 7 (Soccer Ball).

> Once the ball is kicked into the air by the soccer player, it will gradually decrease in speed in an upward motion until it reaches its peak height. From here, gravity will impact on it and cause it to fall to the ground at a faster rate than when it was projected in an upward movement.

Many students made incorrect predictions for the two balls launched simultaneously in task 13. Students influenced by impetus theory naturally selected the ball which was released and fell vertically downward as the ball which would reach the ground first. According to their theory, the other ball would (need to travel horizontally outwards for a time before (at some critical point) descending. For example, Rochelle and Jilly reasoned: "The ball on the left will have to move out before falling, while the ball on the right will fall straight down." Kirstie and Jenny held similar views: "The ball on the left will have to go horizontally before falling vertically, whereas the one on the right will only have to go vertically and straight to the ground."

Tasks 14 and 15 contained the only video clips depicting laboratory-based equipment. The challenging nature of these tasks proved to be motivating for the students and generated much interest and discussion (see section 6.1 for example). Conceptually, it was quite similar to the sailing boat problem as students were asked to consider a projectile launched from a moving carrier. As in task 12 (the Sailing Boat), most groups predicted that the ball would land behind the moving cart and many were genuinely surprised when they saw the launched projectile follow and land back in the cart. Kirstie and Jenny's reasoning was typical of most students' views here, explaining that "the ball is projected vertically upwards which thus means it will shoot straight up and then fall straight back down behind the moving object." Bob and Rick made a correct prediction but again used their force implies motion theory when they predicted that the ball would land back in the cart "because the ball will have a forward motion force."

7.2.4 Summary

Students' written responses and drawings revealed many common pre-Newtonian alternative conceptions that were consistent with the literature in this field. The three tasks depicting vertical motion elicited alternative conceptions of gravity near the earth's surface as well as the Aristotelian belief that heavy objects fall faster than light objects. The tasks depicting projectiles launched from a moving carrier were a major problem for many students and strong impetus related views emerged here. The terms *momentum*, *energy* and *force* were commonly used by students to imply an impetus property—again consistent with past studies (e.g., Halloun & Hestenes, 1985a; McDermott, 1984; Whitaker, 1983). The term *propulsion* also was used in class 2 for the same purpose. The 'straight down belief' (McCloskey, 1983a), otherwise known as the 'zero velocity' response (Millar & Kragh, 1994) was prevalent in both classes. The Aristotelian 'law of support' belief was evident amongst a few groups through their responses to tasks 4, 5 and 6. However, the mass and speed variations in these tasks (as in the cup and ball tasks) elicited many impetus related beliefs, often resembling those from medieval theorists.

7.3 Conclusion

Data from this section of the study showed that student' interactions with the computer-mediated POE tasks revealed a wide range of alternative conceptions that were consistent with the literature in this field. It was no surprise that many of the students' conceptions emerged in the prediction stage of each task as the multiple-choice options were informed by past physics education literature. However, the students' written reasons and drawings also provided a rich supplement to their multiple-choice responses.

Most of the views elicited related to naive impetus theory and alternative conceptions regarding the nature of gravity. The heaviness and speed of projectiles were a common concern for many 'impetus students', and the critical level at which gravity starts to dominate the objects' path also was of interest. Most students believed this critical level occurred at the point at which gravity is roughly equivalent to the amount of impetus in the projectile—similar to Albert of Saxony's 'compound impetus' theory from 14th century (refer to section 3.2.2). Both passive and active projectile launches seemed to elicit associated alternative conceptions for many students and these were consistent with other studies (e.g., Fischbein et al., 1989; McCloskey, 1983b).

The large variety of students' alternative conceptions reported in this chapter was elicited in the unique context of two classes using multimedia-supported POE tasks as probes of understanding. Teachers perceived these tasks as an efficient and effective way of eliciting students' science views.

CHAPTER 8

TEACHER AND STUDENT PERCEPTIONS OF THEIR USE OF THE MULTIMEDIA SUPPORTED POE TASKS

8.0 Overview of chapter

This chapter addresses the teacher and student perceptions of using a computer-mediated environment to engage in the predict–observe–explain strategy. The main research question relevant to this chapter is given below, along with three subsidiary research questions:

Research Question 3:
What are the perceived affordances and constraints of the computer-mediated environment for the predict–observe–explain strategy?

Subsidiary questions:
I. What are the student and teacher perceptions of the level of student control of the POE tasks?
II. What are the student and teacher perceptions relating to the use of the digital video clips to observe the events in the POE tasks?
III. What are the student and teacher perceptions relating to the use of the digital video clips to enhance relevant contexts in the POE tasks?

Discussion directed by these research questions is based around three general assertions directly related to the three subsidiary research questions. Findings are supported by data from interviews, survey responses and sample critical incidents from the recorded conversations between students.

8.1 Assertion One: The computer environment afforded student control of the pacing of the POE strategy, allowing more flexibility for students to discuss their views and contributing to high levels of ownership of responses.

The multimedia program effectively scaffolded the POE strategy, allowing students to progress through the POE sequence by themselves and permitting control of the demonstrations via the digital video medium. These affordances gave students more opportunities to express their own views and gave the teachers more opportunities to hear these views. Both students and teachers perceived this extra control over the POE tasks as a source of student motivation.

8.1.1 Teacher perceptions

Student control of the POE tasks was a main issue emphasised by both teachers. In her interview, Judy emphasised that her students enjoyed being in control of the pacing of the POE strategy, in contrast to teacher-centred POE tasks. For her, this extra student control had positive implications for students of varying abilities in her classroom:

> I think they really enjoyed being able to work at the pace of just their small group. If I were trying to demonstrate these things in class, everyone would have to work together. Like I couldn't go on to the next one until everyone was ready. I think they really enjoyed that because there's a reasonable range of abilities within the class. (From interview with Judy)

Wayne also believed that the boys in his class enjoyed being in control of the POE tasks. In his interview, he emphasised "that they particularly enjoyed being in control of the process, which is pretty rare in classrooms." He believed the student control of the feedback process (via the video clips) was important too: "They get immediate feedback, which they like as well." Judy believed this extra autonomy had a positive effect on the girls' confidence and comfort levels and hence encouraged discussion:

> Kids can go over and over as many times as they like as slowly as they like. I think that's really important with girls to take the pressure off them—that they have to have the right answer instantly because they do like to think about it and discuss it and feel confident that they have seen the right thing. (From interview with Judy)

Judy perceived this student control over the POE tasks as ultimately allowing her to probe students' views further. The small student-centred groups allowed most students to voice their opinions and be heard by the teacher through their written responses.

> I would never have been able to do those demonstrations in two lessons and get feedback from each individual student about what they thought was going on. You can't listen to twenty girls at the same time when they're saying things to you in class—or remember it! (From interview with Judy)

Responses to survey questions (see Table 8.1) were consistent with feedback from the teachers' interviews. They both perceived the higher level of student control as desirable (see items 50 and 57). Responses to items 57 and 70 confirmed that both

Table 8.1

Teachers' responses to items relating to student control from the survey: Reflections on the POE Computer Tasks (n=2)

Survey Item	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
50. Students found the computer program frustrating. They would prefer to do teacher-led POE tasks.	*Wayne* *Judy*				
57. I felt powerless having a computer present the demonstrations.	*Judy*	*Wayne*			
66. The students enjoyed manipulating the video clips.				*Wayne* *Judy*	
70. I would prefer to lead the students through live POE demonstrations myself.		*Wayne* *Judy*			

teachers appreciated the student-centred nature of the tasks. It was interesting that both teachers indicated a preference for this extra student control compared to teacher-led POE tasks.

8.1.2 Student perceptions and critical incidents

Students enjoyed being in control of the whole program, progressing through each POE sequence at their own pace and manipulating the video-based demonstrations to make their observations. This was evident in the classroom observations, survey responses and comments made during interviews. For example, Kirstie strongly believed that she had more input into the conversations about the demonstrations because she was working with one other person rather than a whole class:

> You feel like it's your input. Whereas if you're doing the whole class and the teacher's dropping the ball [for example] your say isn't necessarily what comes across because everyone's throwing their own thing in. You don't miss out on having a say [working in pairs]. (From student interview with Kirstie and Jenny)

From Kirstie's perspective, the extra student control led to a heightened level of ownership of her responses. The following dialogue between Cath and Michelle was typical of students' allegiance to their predictions as they anticipated the feedback through the video clips:

Cath: I bet you we were wrong! (Leaning forward, waiting for the film)

Michelle: Probably.

Cath: I don't want to see. I don't want to watch!

(Students watch video clip intensely)

Michelle: Is that B? What position is that?

Cath: It's position B!! It's position B!! (Said proudly in an excited tone). It's B I can tell you. That's great!

These enhanced levels of ownership contributed to interesting reactions when students viewed unexpected outcomes. For example, Laurie and Sam did not expect the balls to hit the ground at the same time in task 13 (Two Balls Falling). Laurie stated: "Oh no way! Sam replied, "That's weird!" Joan and Leigh experienced similar disappointment as they observed the outcome in task 8 (The Ball and Swing): Leigh exclaimed: "Oh—there we go!" Joan responded: "Oh we were wrong!" before Leigh reiterated her initial comment in disbelief: "We were wrong." Indeed, the following entry was made in the field notes from the Year 11 computer sessions:

> Claims of 'I was right' and 'I told you' and other exclamations also were often heard through the session. Arm raising accompanied by calls of 'Yes!' and other triumphant expressions and gestures were seen by this researcher as students observed the outcomes from the videos and compared these with their predictions.

Although an element of surprise contributed to some of these reactions, many expressions appeared to be amplified by the students' high levels of ownership of their predictions.

The extra control of the POE tasks was important for Jenny, who expressed the following sentiments in her interview: "You don't have to ask the teacher to do it again, or have to wait for other people or whatever else." Indeed, Mick and Pierre enjoyed manipulating the demonstrations according to their own needs. In their interview, Mick mentioned: "You can repeat [the video]...what you need it for." Pierre then commented: "You can control it. You can do what you want; you don't have to just watch them." Dave said he liked having extra time to observe the demonstrations at their own pace: "You can replay as many times as you like. Play in slow motion or frame-by-frame. Where as with the teacher, you blink and it's gone. You do it in your own time." Alison also found it motivating to be able to control the demonstrations: "I thought it was good because it was interactive so it made educational things interesting."

Responses to items 39 and 58 in the student survey (see Table 8.2) indicated a strong student preference for small group settings when engaging in POE tasks.

Table 8.2

Students' responses to items relating to student control from the survey: My Experience Using the POE Computer Tasks (n=46)

Item	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
11. I found the video clips hard to control	23	16	5	2	0
39. This computer program was frustrating. I prefer doing teacher-led POE tasks.	12	25	7	1	1
47. I didn't enjoy manipulating the video clips.	13	27	4	2	0
58. I prefer to discuss demonstrations in a big class group led by the teacher, rather than with a partner on a computer.	7	27	6	6	0

Responses to item 39 seemed to indicate that students generally perceived the computer environment as most compatible with the POE strategy.

8.1.3 Summary

Use of the computer program in small groups effectively created a student-centred learning environment allowing students to control the pace they worked through the POE tasks and also allowing them to control the presentation of the video-based demonstrations. Students and teachers perceived this increased autonomy as resulting in more time for students to discuss responses, leading to enhanced levels of ownership of predictions and more opportunities for teachers to hear students' opinions.

8.2 Assertion Two: The digital video medium provided a sophisticated tool for students to make detailed observations, enhancing the quality of feedback on their predictions. Film quality and credibility were possible constraining factors discussed by students and teachers.

Both students and teachers perceived the digital video medium as an important tool facilitating their observations of the physics demonstrations. Students made clinical and detailed observations using the sophisticated digital video facilities, receiving valuable feedback on their predictions. The quality of some film clips and the level of student belief in the films were raised as potential concerns and represent potentially constraining factors in the use of digital video clips in POE tasks.

8.2.1 Teacher perceptions

Judy perceived the digital video facilities in the program as being most useful for students. She believed that students in her class found it easy to use the digital video clips to closely observe the scenarios presented. She witnessed many groups of students using the sophisticated video tools available to them, including playing in slow motion, rewinding and playing frame-by-frame. This was in agreement with classroom observations and also comments made during student interviews. During her interview, Judy compared the digital video medium with analogue VHS players and live demonstrations:

> I thought it was really good on the computer how easy it is to play and replay and control them [the video clips] frame-by-frame. I've never found that very easy on a normal video recorder and you certainly can't do that in a live demonstration. (From interview with Judy)

In the same interview, Judy also contrasted the use of digital video clips with some live POE demonstrations she did in a previous class. In that lesson, she used ticker-timer tapes to show constant speed, decreasing speed and increasing speed. She discussed the time-consuming preparation involved in attempting to produce identical tapes for groups to discuss and observe. She also compared these cumbersome ticker-tape demonstrations with the ease and accuracy of reproducing identical, visible results for all students using digital video clips.

> I had to make some reliable tapes before the lesson just in case something went wrong with the ticker tape or I didn't pull it through properly or whatever, so there was a fair bit of preparation to be done. Even then there was those bits of ticker tape that the girls got that looked like the dots were impaired and they thought that was how it was meant to be. So there is a problem with mass-producing perfect results for them to look at which you don't have on the computer.

Wayne was also impressed with the option for students to see exact clones of demonstrations and emphasised how easily and frequently the students in his class replayed demonstrations. In his interview, he commented that as a teacher, he could not possibly provide such an accurate replication of a live demonstration:

> I suppose the advantage is that they [the demonstrations] are clean—bang—you get the potted view of what's going on and there it is there...and you can replay the same thing so it's like doing the experiment again, having set it up precisely. So you see the same thing again and again and again. You can talk about that at various levels. So I think it's pretty

> useful. It saves time, it allows complete reproducibility and therefore it's something that you can discuss from that level of saying that we're going to get the same result if we do it again. (From interview with Wayne)

Judy gave an interesting insight into girls' education in her interview. In her considerable teaching experience with girls, she had come to the conclusion that they often neglected careful observation of everyday science phenomena, especially physics phenomena. She believed that for various reasons associated with gender stereotyping, girls were not encouraged to observe such phenomena as young children:

> The one thing that I think girls often suffer from is that they haven't been keen observers of dynamical situations in their lives because from small children they often haven't been given toys to play with that encourage those sorts of skills. So even though all of these situations should be familiar to everyone, they may not have ever observed carefully what actually happens. (From interview with Judy)

For example, Judy was surprised about her students' responses to task 6 (Car Launch). She observed that students were linking this task with movie scenes. Audio recordings from numerous groups revealed these references included scenes from the films 'Speed', 'Mad Max', various 'James Bond' movies as well as cartoons! However, Judy was amazed that despite the students' apparent familiarity with scenes from these movies depicting cars launched into the air, crashing over cliffs, etc., they still made many incorrect pathway predictions.

> One of the things I was surprised about—considering the number of movies that they watch where cars crash through things and over barriers—I was really surprised that they didn't all get task 6 perfectly right. That really surprised me because that relates to TV, their major form of observation and to me it indicated to me how passively they observe.

This was an important comment in the context of this research as one of the objectives of using the digital video clips was to initiate links between the tasks and students' experiences. As well as commenting on the students' limited observation skills, Judy was implying that the digital video provided, perhaps for the first time, a lens for the girls to more closely observe everyday phenomena.

Survey data were again in agreement with comments made during teacher interviews (see Table 8.3). Both teachers generally perceived the video clips as a useful facility for observing physics phenomena. The subject of item 41 was a contentious issue for Judy. On a couple of occasions, she was questioned by students who were unsure of the outcome of a task. In particular, she expressed reservations about the film quality in task 9 (The Astronaut) and task 15 (Cart and Ball II). This issue of film quality is addressed in section 8.2.2.

Table 8.3

Teachers' responses to items relating to student observations from the survey: Reflections on the POE Computer Tasks (n=2)

Item	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
14. The students often used the video tools (play, rewind, pause, slow motion, etc.) to carefully observe each video clip.				*Wayne*	*Judy*
17. Students found the video clips hard to control.		*Wayne* *Judy*			
41. The outcome of each POE task was easy to observe from the video clips.		*Judy*		*Wayne*	
65. Students found it difficult to observe the outcomes of the video clips. Real-life demonstrations are much easier to observe.		*Wayne* *Judy*			

8.2.2 Student perceptions and critical incidents

Jessica and Alison found the video clips were easy to manipulate and appreciated the option of using slow motion to observe the outcomes of the demonstrations. Their level of conviction was enhanced by the use of the video facilities, as mentioned in their interview:

Jessica: I think having video clips was good—it was easier.

Alison: It [the video clips] demonstrates how it happens, not just like a textbook where you read this happens and you don't see it.

Jessica: Also you can have it in slow motion.

Alison: You can actually see what's happening. Also you can work out why it's happening from just seeing it. It's just easier to imagine; it's easier than just seeing a picture because you actually see that it does actually happen.

For Alison, the clips provided a source of meaning that was lacking in her physics textbook. She perceived the video clips as providing an extra level of credibility, initiating a deeper level of thinking about associated phenomena. Kirstie expressed similar sentiments in her interview, making an interesting comparison between the video clips and the stroboscopic photographs found in many physics textbooks:

> It helps a lot because you can replay it slowly backwards and forwards. It helps instead of watching someone throwing a ball up in the air and wondering what happens. Say if you

> have photos of a movement—you miss out parts. With a video it's like a continuous movement, you don't miss any section of it. (From student interview with Kirstie and Jenny)

Kirstie obviously valued the realistic element of the video clips and like Alison, appreciated a greater level of conviction from the video medium. Pat and Dave also utilised the digital video facilities to observe the outcomes of the POE demonstrations. In his interview, Pat recalled how he observed the outcome of task 1 (The Falling Ball), which showed a person dropping a ball from shoulder height. Pat's account illustrated how he used the frame-by-frame feature to make clinical observations of the ball and infer that it was increasing its speed as it was falling:

Pat:	You can sort of pinpoint times and freeze it right there...with the frame-by-frame. For example when the balls are falling down, you can actually see how they progressively pick up speed. Where as if you drop it, it's just milliseconds and it's gone.
Interviewer:	How did you know the ball was speeding up?
Pat:	Frame-by-frame. Just click, click, click. Each frame the ball was further and further down the page. The first frame it had only fallen just a little bit; the second frame a little bit more.

The audio recording of Pat and Dave during their observation of task 1 supported these claims. As Pat played the video, Dave stated: "It's just moving faster, you can tell—see." Pat then made the following response while using the step-frame facility: "Look at each frame: small distance—small distance—getting a lot further and further apart—the ball is obviously increasing its speed." Joan and Leigh used the same video tools to observe the ball falling in task 1:

Joan:	It's getting faster isn't it?
Leigh:	Yeh—I think so. I think as it goes frame-by-frame it gets... (She plays the video using the step-frame facility)
Joan:	It gets faster!
Leigh:	I think as it goes down, the space that it drops is bigger...
Joan:	Yes, in each frame, the length—uh—the size of the drop— the length of the drop is longer.

The students' conversation here was supported by the video capabilities. The last two observations were particularly thoughtful and detailed and were made possible by the video tools. Pat again used the step-frame and slow motion replay facilities to eventually convince Dave of the outcome for task 3 (Ball Launch):

Pat: OK. We've got to go frame-by-frame. Keep watching, it's going out.
Dave: It's going down now.
Pat: How is it compared to that [prediction]? Ready? (Pat plays frame-b- frame) Don't you think it goes out more first? Check it out.
Dave: She drops her hands so it looks like it's actually going down faster.
Pat: Yeh—but you don't have to look at her hands. Just look at the ball. At the start, look at the start again. It goes sort of out heaps.
Dave: OK. How's that? (Questioning Dave's observations)
Pat: It sort of goes up first. Watch again (Pat replays the video clip in slow motion). See, she's let it go. Now it's going up and then it slowly starts coming down.
Dave: You draw it. (Sounding not quite convinced)
Pat: OK - check it out again. (Pat again replays video clip in slow motion) Yeh...
Dave: Yeh, it goes down. (Sounding more convinced)
Pat: Do you reckon it gets almost vertical?
Dave: No...
Pat: No. How's that then? (Showing Dave the drawing)
Dave: That's good.

Dave's observations here seemed to be enhanced by Pat's video-mediated explanations. Indeed, this episode was a good example of Jessica and Alison's earlier claims that the video medium augmented their levels of conviction when observing demonstrations.

Like her teacher, Belinda appreciated the opportunity to observe an exact replica of each demonstration as many times as she wanted. In her interview, she stated: "If you want to play it again it will be exactly the same. For example, if you drop a ball live your hand could be higher the second time." Kirstie also mentioned this aspect of the digital video medium in her interview: "You see someone throwing a ball and you miss it and they have to throw it again, it may not be the same."

Students' responses to relevant survey items (see Table 8.4) indicated that the digital video medium was easy to manipulate and most useful for their observations. Most students found the replay and slow motion facilities useful, in agreement with class observations. Responses to item 38 were significant: students perceived the replay facility as a useful one for convincing themselves of task outcomes. This perception agreed with Wayne's previously discussed thoughts about the ability of the video medium to replay exact replicas of demonstrations. Data from classroom

Table 8.4

Students' responses to items relating to student observations from the survey: My Experience Using the POE Computer Tasks (n=46)

Item	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
22. I found it easy to observe the outcome of each POE task from the video clips	0	2	6	28	10
32. It was really useful to play the video clip in slow motion.	0	4	2	23	17
38. I often replayed the video to make sure of the correct outcome.	0	2	0	31	13
55. I found it difficult to observe the outcomes of the video clips. Real-life demonstrations are much easier to observe.	3	19	13	9	2

observations indicated that students found this replay operation particularly useful for improving levels of conviction of an outcome after incorrect predictions had been made. Responses to item 55 indicated that many students believed they had a better view of most of the demonstrations through the use of the digital video medium.

A few students and one teacher criticised the film quality of some video clips and said that it impeded their observation of the outcome of some demonstrations. Joanna, Melissa and Belinda found the film clip in task 9 (The Astronaut on the Moon) difficult to see because of the age and quality of the film clip. At one stage they were unable to differentiate between a ball and a screen pixel! There also was a problem with the perceived 'frame of reference' in task 7 (Soccer Ball) for Clare and Evelyn. In this film clip, the camera used to film the soccer ball zoomed too close to the ball, losing the background trees and other static items on the ground that were creating a frame of reference for the ball's motion. The camera also moved horizontally in the same direction as the ball for a time period, slightly distorting a clear observation of the shape of the ball's pathway. Indeed, in her survey, Evelyn mentioned this problem: "I hoped that this video clip [in task 7] had more space so we can see the whole thing." Her partner Clare also explained: "One of the video clips was someone kicking a ball. I think it would be better to have a bigger image so the camera doesn't have to move [and then] we could observe better." Unfortunately (rather naively in hindsight!), this problem was not identified during the development of the program.

Task 15 (The Cart and Ball) also became an interesting exercise in observation. In this task, the cart is travelling down an incline and fires a ball into the air at an angle of 90 degrees to the incline while continuing to move down the incline. Students had to predict whether the ball would land back in the cup. The video of this demonstration was taken using stroboscopic techniques and when viewing the video at normal speed or slow motion, the ball appeared to land back in the cart. However, after toggling the video clip frame-by-frame, a few students realised that in fact the last snapshot of the ball in the film clip occurs just before the ball reaches the cart. There was no evidence in the video clip that the ball actually lands back in the cart! Although this was totally unknown to the researcher during the design of the program, the task became an interesting exercise in who was observant enough to notice this dilemma. It also was a source of great debate within groups. For example, Jane and Anne were surprised when they viewed the film clip of this task and after replaying the clip many times, they disagreed on the outcome:

Anne: Did it go back in the cart?
Jane: Yes it did.
Anne: Did it? Play it again. Didn't it [the ball] go over the top of it (the cart)?
Jane: No. It runs in. See! That's it; you can see it go in.
Anne: No it doesn't! The cart's just there.
Jane: No—see. Go back one frame. See it goes in!
Anne: Going in where? There's nothing there. It [the cart] is over there and the ball's there.
Jane: That's not the ball.
Anne: Yes it is. See, look when we go back a frame—and now go forward (a frame).
Jane: See it's going in!
Anne: We need a second opinion!

Jane and Anne continued to debate the outcome of the video clip until calling the teacher for help. The teacher complimented them on their close analysis of the scenario and asked them to make up their own minds. Cath and Michelle discovered the same dilemma in this task:

Michelle: Oh—would you believe it?
Cath: It landed in the same spot! (Replaying video frame-by-frame) ... It didn't actually; look!
Michelle: Yeh—it landed in the actual...
Cath: No—its right above it [the cart] there, then it just vanishes.
Michelle: Oh yeh!

Both groups were undecided about their response for this task and consulted the teacher for guidance.

The credibility of the digital video clips also emerged as an important issue. Indeed, as the students' level of belief in their own observations will naturally (at least partially) depend on their perceptions of the video clips' credibility, this is a core issue for consideration of the video medium in the POE strategy. For example, how do the students know if a video clip has been edited? A few students touched on this topic in their interviews. Joanna did a reality check with her own experiences to assess the credibility of the clips. (Indeed, this was one of the intentions of using video clips of real-life events). She used the realistic contexts to assess the authenticity of the clips: "You can usually link most of the things that happened to everyday life. You kick a soccer ball and [you know] it goes up and comes down." Alternatively, Jessica trusted her teachers: "Yes. It doesn't seemed to be rigged you know. It's a teaching thing—I don't think they'd do that [use edited video clips]."

8.2.3 Summary

The digital video medium provided a wider lens for students to observe events presented in the POE tasks by helping them to make more profound interpretations of their world and more elaborate descriptions of their ideas and views. The sophisticated tools inherent in the medium allowed the students to make detailed and clinical observations of phenomena and hence receive valuable feedback on their predictions. The step-frame facility and slow motion replay were particularly useful for convincing students of outcomes. From the perspective of observing phenomena, two crucial and potentially inhibiting factors were the quality and credibility of the video clips. Screen resolution, use of appropriate camera angles, panning and zooming strategies and accurate use of stroboscopic techniques in the development of these film clips emerged as important issues relating to film quality.

8.3 Assertion Three: The rich contexts supported by the digital video medium were engaging for students and generally helped them feel comfortable and confident, particularly in the initial prediction phase. However, teacher intervention was sometimes lacking and became necessary to supplement written descriptions and video previews of these rich settings before valid predictions could be made.

Teachers and students perceived the everyday contexts in most of the video-based demonstrations to be interesting and relevant. Students acknowledged that these contexts helped them to relate physics to the real world. One teacher believed the contexts created a degree of comfort amongst students, helping them to consider their predictions with confidence. Despite great care in the program design stage, some contexts created a degree of confusion in a few tasks, sometimes leading to students creating excuses for incorrect predictions.

8.3.1 Teacher perceptions

Judy saw the rich contexts of the video clips as another factor that was important for her students' confidence. She believed that the everyday contexts of most of the clips helped her students to feel comfortable, especially in the initial prediction phase of the POE sequence.

> I think that's the good thing about them—it didn't make them feel inadequate or nervous—because they were all fairly comfortable contexts. They felt comfortable in trying to make a prediction about the contexts. Where as if they were all laboratory equipment situations, I think by the end of 16 tasks they would have started to feel 'this is too hard for me.' (From interview with Judy)

Responses to relevant survey items (see Table 8.5) indicated that both teachers found the realistic contexts to be a positive feature of the POE tasks. They perceived the rich contexts to be interesting for the students (see for example, items 33 and 67).

Table 8.5

Teachers' responses to items relating to context from the survey: Reflections on the POE Computer Tasks (n=2)

Item	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
9. The computer environment made the POE tasks unrealistic and artificial.	*Judy*	*Wayne*			
33. The digital video clips were more relevant to the students than pictures in textbooks.					*Wayne* *Judy*
44. The video clips were dull and boring for the students.	*Judy*	*Wayne*			
46. The computer tasks were quite irrelevant and meaningless for the students.	*Wayne* *Judy*				
55. The video clips helped students to relate physics to the real world beyond the classroom.				*Wayne* *Judy*	
67. The digital video clips provided interesting contexts for the students to consider motion concepts.				*Wayne* *Judy*	

Responses to item 55 indicated that both teachers believed the everyday contexts helped students to forge links between 'school physics' and the students' real world—one of the purposes of the program.

8.3.2 Student perceptions and critical incidents

The students also appreciated the everyday contexts provided in most of the video clips. When asked about the purpose of the program during her interview, Belinda reflected: "...to let us know that that this stuff can actually be good physics. [Stuff] that you wouldn't normally do." Joanna expressed similar sentiments, reiterating (her teacher) Judy's notion that girls in her class could improve their observation of everyday phenomena: "I think that basically this program shows us physics in our daily life that we didn't really pay attention to." For Mick, the program was an opportunity to observe new and unusual science events: "[The program was] an introduction I suppose. It showed us practical work, motion. Things you can't do like the sailing boat and the astronaut—[things] you can't really show us." These perceptions also were reflected in students' responses to relevant survey data (see Table 8.6). Item 21 elicited a particularly strong response from both cohorts. Indeed, responses to item 33 (refer to Table 8.5) revealed a similarly strong response from both teachers on this same subject—reiterating the earlier point made by Alison (refer to section 8.2.2) that students generally found these types of contexts more interesting than those presented in their textbooks.

Table 8.6

Students' responses to items relating to context from the survey: My Experience Using the POE Computer Tasks (n=46)

Item	*Strongly Disagree*	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
20. The video clips helped me to relate physics to the real world beyond the classroom.	0	1	8	32	5
21. The digital video clips were more relevant to me than pictures in textbooks.	0	0	4	27	15
29. I found the computer tasks quite irrelevant and meaningless.	9	29	5	2	1
37. I found the video clips dull and boring.	5	27	9	4	1

Despite great care taken during the development of the program to avoid ambiguous language and contexts, some students found that the initial description of the physical setting in each task was occasionally insufficient for them to make a valid prediction. For example, Kirstie's experience with sailing actually made her prediction for task 12 (The Sailing Boat) more complicated, as she mentioned in her interview: "At home we've got sailing boats and normally you have other factors such as wind and it would push the ball back—you think you should consider it but you're not quite sure." Despite a video preview of the setting, Kirstie and Jenny thought that outside factors such as wind, could also affect the results of task 14 and 15 (the Cart and Ball tasks). They also were not sure of the setting for task 13 (Two Falling Balls). They wanted to predict that the balls would not fall at all as they thought the dark background in this video clip indicated an outer space setting! (Indeed, the setting for a previous task—task 9—was on the moon with a similar background.) Dave also commented on the Two Falling Balls task in his interview. He thought that the balls might be on a string! He also was not sure exactly how fast the balls were rolling off the tables in tasks 4 and 5 and felt that this uncertainty affected his confidence in the prediction stage.

Confusion over a few contexts affected the reconciliation process after some students observed the video clips and discovered they had made an incorrect prediction. For example, wind-effects also were a problem in task 12 (The Sailing Boat) for Alison and Jessica and were used as an excuse for their incorrect prediction. After observing the outcome of the task 12 video demonstration during the computer sessions, Alison exclaimed: "Oh my God. It fell straight down. That's so weird!" Jessica replied: "It's the wind!" Jessica also strongly believed that the ball in task 10 (The Heavy Ball and Cup) would fall into the cup. After observing the outcome from the video clip, she acknowledged that she was wrong in this instance, but was convinced that if the object was heavy enough, it would fall into the cup (a common alternative conception). Although this is an example of a student strongly holding on to her prior conceptions, detail on the composition of the ball was lacking for her in this task: "We could have underestimated the weight of the ball. If it was lead, it would have gone straight down [into the cup]."

In contrast to most laboratory-based settings where many external variables (such as wind) may be controlled, the out-of-class contexts often needed a high level of detailed description, possibly accompanied by a brief video preview of the setting, before students could make valid predictions. Even these measures were sometimes insufficient for some students and teacher intervention was necessary to clarify any doubts about the settings of tasks. However, this intervention often did not occur and resulted in students using 'excuses' after discovering an incorrect prediction. It should be noted that this is not a problem in teacher-led POE tasks and represents a constraint for the use of small group, computer-mediated POE tasks. In traditional whole class situations, the teacher gives a verbal description of the task setting at the initial stage of the POE strategy. Students can ask questions and the whole class benefits from any further clarifications from the teacher. However, in these student-centred, computer-mediated tasks, the written descriptions and video previews of the task settings become absolutely crucial if students are to make valid predictions. If these settings involve rich, complex contexts, teacher facilitation may be required to supplement these descriptions.

8.3.3 Summary

Teachers and students appreciated the opportunity to use out of school contexts in the video clips. Judy in particular thought that these contexts generally helped her students to feel comfortable and confident in making their predictions. The rich contexts afforded by the video medium required careful and elaborate description before students could make valid predictions and avoid making 'easy excuses' for incorrect predictions. Suitable teacher contact was sometimes lacking for some students when becoming acquainted with task settings in this study. Resulting problems discussed in this section highlighted the importance of teacher facilitation during this initial stage of the POE strategy.

8.4 Conclusion

The computer-mediated POE tasks had a positive influence on student autonomy, and control over their learning environment. The digital video clips provided a lens through which students could make detailed observations of interesting, realistic contexts, providing valuable feedback on their predictions. These affordances helped students to articulate their views with confidence.

Use of the computer environment to support the POE tasks had a noticeable impact on the classroom environment. Students engaged in the tasks in small groups instead of a whole class situation, giving them more control of the POE tasks on two levels. Firstly, students could control the pace of the whole POE strategy, giving them the time and confidence to thoroughly discuss predictions, reasons, observations and explanations. In Judy's opinion, this created a more comfortable atmosphere for her female students to confidently discuss their opinions and views. She perceived that this level of student control led to quality feedback about the students' views, which ultimately allowed her to probe their ideas in detail. Students perceived this control as contributing to enhanced levels of ownership of predictions. Data from class observations and audio recordings supported this claim. Secondly, students could control and manipulate the actual demonstration because it was presented through the digital video medium. Again, this control gave students the time and confidence to articulate their observations.

The digital video medium provided a sophisticated tool for students to observe phenomena in the crucial observation stage of the POE strategy. Students and teachers perceived the slow motion, rewind and step-frame facilities inherent in the video medium as most useful in making clinical observations of events and convincing students of outcomes. They valued the ability of the video clips to replay exact replications of demonstrations. Judy was particularly impressed with the way the video medium helped her students to closely observe everyday phenomena.

Both teachers acknowledged the ability of the digital video clips to present realistic, time-consuming demonstrations that would be difficult to set up in a classroom. Students in particular appreciated the ability of the video clips to present real-life, unusual or perhaps dangerous demonstrations, creating interesting contexts for them to think about science. Despite detailed written descriptions and video previews used to communicate task settings to students, the rich contexts sometimes created confusion, hindering accurate predictions and impeding the explanation phase after conflicting observations. This problem highlighted an important role of the teacher in these student-centred, computer-mediated POE tasks—helping students to become completely familiar with task settings before they make their predictions.

The credibility and quality of the film clips was an important issue for students and teachers in this study. Students unanimously agreed that the clips were authentic and their teachers would only allow unedited footage of real-life events to be the focus of such POE computer tasks. As many of the clips focussed on everyday phenomena, students could easily consider their own experiences of reality to check this authenticity. However, future research in this topic could focus on the effect of students filming their own video footage of events for inclusion in POE tasks, similar to the learner-shot video laboratories described by Squires (1999). For example, task 1 (The Falling Ball) could easily be filmed by students as a subject for further consideration in a POE task. Students also perceived the quality of the video clips as important. The unexpected dilemma faced when observing the stroboscopic video clip in task 15, and the frame of reference problems created by the inappropriate panning and zooming in the task 7 video clip, highlighted the importance of choosing appropriate techniques when making video clips for these purposes.

The students and teachers perceived many affordances and constraints of the computer environment for the POE strategy. The computer-mediated tasks afforded new opportunities for students in the crucial observation stage, enhancing the quality and detail of feedback to students after making their predictions. They also allowed learners to proceed through the POE strategy at their own pace, granting students time to discuss and reflect on their views. The real-world contexts made available through the use of the digital video medium were generally perceived as helping students feel confident and comfortable in voicing their opinions, particularly in the initial prediction phase. However, a few potentially constraining factors emerged. Any benefits relating to the use of digital video clips for student observations could be jeopardised by inappropriate filming techniques, poor film quality or low credibility levels. Additionally, the rich contexts made possible through the use of this medium demanded detailed written descriptions and video previews in the initial stage of the

POE tasks. Teacher facilitation is a necessary supplement to these written descriptions if students are to acquaint themselves with these rich settings. Overall, the data presented in this section of the study represents a positive development in the use of the POE strategy in science classrooms.

CHAPTER 9

SUMMARY AND CONCLUSIONS

9.0 Overview of chapter

This chapter provides an overview of the study, re-stating the three main research questions and justifying the interpretive methodology used to explore them. It summarises the main findings before discussing the significant issues and recommendations emerging from the study. Finally, limitations and directions for future research are presented.

9.1 Introduction

According to Salomon and Almog (1998), we live in an age of "constructivist, socially shared, situative, technology-intensive learning environments" (p. 233). Indeed, a review of the science education literature informed by constructivism indicates that good learning is a process of socially-based, active co-construction of contextualised knowledge. There has been a demand for appropriate investigations of these types of environments. For example, Kozma (2000) called for more research on the impact of technology environments on the cognitive processes and social practices of science learning. Indeed, Harper and Hedberg (1997) challenged researchers to "demonstrate for developers how to capture these opportunities and support the intrinsic motivation of learners to explore their own world and the variety of viewpoints within it" (p. 15). They also identified a need to further investigate facilitative strategies that support learners in socio-cultural processes. The present study attempts to add to the knowledge base of these types of technology-mediated science learning environments by investigating the collaborative use of computer-mediated POE tasks for the purpose of eliciting students' conceptions and promoting discussion and reflection on these views. Although the POE strategy is well explored in the literature, this particular use of the POE strategy has not been reported. Indeed, the use of digital video clips to present demonstrations as stimuli in these multimedia-supported tasks represents a pioneering development in the use of the POE strategy.

The design and development of the program used in this study was reported in chapter 4 to enable a deeper insight into the study's findings and to facilitate a full understanding of the methodology issues described in chapter 5. The program was created and evaluated by the author over a six-month period leading up to the data collection period of the study. Constructivist theory and related literature from both the science education and educational technology fields informed the creation of the program. For example, aspects of the program were influenced by alternative conceptions research and the history of science literature.

The methodology in this study allowed in-depth insights into the participants' perceptions and interactions but did not attempt to compare media or focus on the technology per se. Instead, the qualitative data sources and their analysis have shown how students from two classes used an emerging and innovative technology in a constructivist learning environment. The focus of the study was on the personal and social dimensions of students' learning and their perceptions of the learning tool. Three main research questions guided this study (and each had subsidiary questions that were discussed and introduced in section 1.2 and also in chapters 6, 7 and 8). Once again, the main research questions were:

1. To what extent do the computer-mediated POE tasks promote meaningful discussion about students' science ideas?
2. Does the students' engagement with the program effectively elicit their personal science views?
3. What are the perceived affordances and constraints of the computer-mediated environment for the predict–observe–explain strategy?

9.2 Summary and discussion of findings

The findings are concerned with the students' discussions at the computer (Research Question 1), the use of the tasks as an instrument to elicit students' science conceptions

(Research Question 2) and the students' and teachers' perceptions of the computer-mediated POE tasks (Research Question 3).

9.2.1 The students' learning conversations at the computer

This section of the study focused on the students' small group discussions at the computer during their engagement with the POE tasks. A social constructivist perspective was adopted to analyse and synthesise these findings. Claims here were supported by quoted conversations between students that represented critical incidents occurring during the computer sessions. These also were supported by data from interviews, survey responses and class observations.

Most students participated freely in meaningful discussions about the science related phenomena in each task. They freely articulated their own conceptions as they engaged in the activities and there were many disputes caused by conflicting views between students. Most students listened carefully to their partner's viewpoint and there were many occasions where students showed strong reflection on the viability of these and their own conceptions. For example, there were many reflective pauses during group discussions and students often asked each other thoughtful and relevant questions. A feature of this section of the study was the widespread incidence of non-verbal communicative acts such as student gestures and off-computer 'mini-experiments' instigated by the POE tasks. Another feature was the high frequency of students editing their (written and drawn) responses sometimes up to three or four times! These collaborative activities often augmented the learning discussions and enhanced reflection processes. Indeed, 'inscriptions' (Kozma, 2000) such as photographs, video clips and student drawings served as an appropriate backdrop to these learning conversations. Although there were some cases of genuine shared meaning-making and co-construction of ideas, such in-depth discussions were less frequent probably due to time and science vocabulary constraints.

These findings are important from a number of perspectives. The computer program was used by the students in such a way that it became more than a probe of understanding. The rich conversations were testimony to the quality of peer learning that occurred during this process of eliciting students' ideas. Hence, these conversations provided an example of learning *with* computers (Jonassen & Reeves, 1996) and collaboration *at* the computer (Crooks, 1999). Indeed, they make a contribution to the literature relating to the CSCL movement (Koschmann, 1994), marking a 're-focus' on recently neglected collaboration issues *within* the classroom (as distinct from collaboration *outside* the classroom through online technologies). These finding are supportive of Kozma's (2000) observations that "these new symbolic systems…may best be used within rich social contexts that prompt students to interact with each other and with the multiple symbol systems to create meaning" (p. 44). Finally, the findings provide some answers to the important question raised by Roth et al. (1996) when they asked how technologies can facilitate collaborative sense-making? Clearly, the computer-mediated POE strategy used in this study facilitated student articulation, reflection and (to a lesser degree) negotiated meaning-making.

It must be noted that the positive results reported in this section of the study were relevant to the prediction, reasoning and observation stages only. Students generally did not conduct rich conversations during the explanation stage of the POE tasks in this study. There are numerous possible reasons for this result. Firstly, students were sometimes pressured for time during the sessions and may have deliberately taken 'short-cuts', avoiding too much engagement in this stage of the tasks. Secondly, there were some instances where students would not admit to incorrect predictions, instead making excuses to 'hang on' to and defend their alternative conceptions. For example, a few students blamed some confusion regarding the initial task setting to avoid making reflections in the explanation stage. Finally, students from both classes were probably used to teacher-led POE tasks where the teacher can provoke and initiate quality comments in this difficult reconciliation stage. Indeed, this raises questions for future research in this area relating to the role of the teacher in these types of computer-mediated tasks (refer to section 9.3.1).

9.2.2 The elicitation of students' conceptions

This section focused on the use of the POE computer tasks as an instrument to elicit students' science conceptions. Teacher perceptions were discussed, followed by a comprehensive synthesis of students' alternative conceptions elicited through their use of the program. It must be emphasised that this was not an alternative conceptions study. This section was attempting to show the effectiveness of the POE computer tasks as a tool to elicit a variety of student preconceptions and hence it was imperative to present these conceptions and compare them with the relevant literature (discussed in chapter 3). Claims in this section of the study were mainly supported by data from students' written responses and drawings. Responses to teacher surveys and interviews also were used as data.

Teachers perceived the POE computer-based tasks as providing an efficient and effective way of eliciting students' science views. A large variety of pre-instructional conceptions were revealed through the students' engagement with the program. From both classes, approximately 300 instances were identified where students' views were considered contrary to the established science view. A speculative reason for this success was the visual and social nature of the students' experience with the program. In many cases, these interactions possibly activated real situation-based prior knowledge—although this would need to be verified by further research.

Many of these conceptions emerged from the reasoning and observation stages as well as the prediction stage. Drawings in particular provided a rich source of data, probably because of their open-ended nature. Most views revealed a variety of pre-Newtonian conceptions that were consistent with the literature—medieval impetus and Aristotelian beliefs are 'alive and well' in modern Australian students! The tasks involving projectiles passively released from moving carriers were a major problem and revealed strong impetus beliefs in both classes. The large mass and speed of the car in task 6 provided a particularly 'inviting' task for impetus theorists! The students' frequent use of the terms *momentum*, *energy* and *force* to imply impetus properties also was in agreement with relevant literature.

These findings add to the body of knowledge about probes of understanding in the science classroom. Peterson and Treagust (1989) identified a need for these types of investigations: "To assist the classroom teacher in identifying alternative science conceptions, it is necessary to develop methodologies that can readily be used by teachers in their class environments" (p. 302). There is no doubt that interviews are the most effective instrument to elicit students' science beliefs but unfortunately they require extra time and considerable interviewer expertise. For example, students can easily be intimidated by the adult interviewer. The instrument used in this study was perceived as efficient by both teachers and the absence of an adult interviewer reduced bias or misleading questions and eliminated student feelings of intimidation. Hence, this study adds to the literature base of practical and viable alternatives to interviews as effective instruments to explore student conceptions in busy classroom situations.

It must be noted that the students' written responses recorded by the computer (as well as their drawings) represented group responses. Although this could be seen as a limitation in this section of the study (refer to section 1.5), it also represents a benefit when compared with other individual probes that produce a massive amount of data for teachers to process. The computer printouts of students' responses were perceived as useful and manageable by both teachers. Hence, this section reveals the successful use of a collaborative, computer-mediated probe of understanding to effectively and conveniently capture students' pre-instructional conceptions.

9.2.3 The students' and teachers' perceptions of the computer-mediated POE tasks

This section explored the perceived affordances and constraints of the computer environment for the POE strategy. The findings have implications for the technology-mediated implementation of the POE strategy in science classes. Indeed, the strong educational technology focus in this section is an attempt to provide some answers to Kozma's (1994) important question: "In what ways can we use the capabilities of media to influence learning for particular students, tasks and situations?" (p. 16). Three main issues emerged from the interview data, survey responses and sample critical incidents from the students' recorded conversations. These issues concerned the learner control of the POE tasks, the use of the digital video medium during the observation phase, and the rich physical settings depicted in the video clips.

Firstly, the computer environment afforded student control of the pacing of the POE tasks and also permitted students to control the presentation of the video-based demonstrations. This extra autonomy facilitated opportunities for students to thoroughly discuss their predictions, reasons and observations and helped elicit conceptions. It also contributed to a high level of ownership of responses. Importantly, survey and interview data revealed that students themselves were aware of this extra control. Hence, the perception of this extra control as a source of intrinsic motivation was not surprising (Becker & Dwyer, 1994).

Secondly, the computer-based digital video clips afforded new opportunities for students in the crucial observation phase of the POE process by providing a refined tool for students to make detailed observations of events, enhancing the quality of feedback on their predictions. Student dyads made clinical and comprehensive observations using the digital video facilities, helping them make mature interpretations of the real world events presented to them and more elaborate articulations of their conceptions. The step-frame, slow-motion and replay facilities were particularly helpful in convincing students of outcomes.

However, despite great care in the development phase of the program, the filming techniques used in some video clips were perceived as constraining factors for the observation of a few demonstrations. Camera angles, panning, zooming and stroboscopic filming techniques were all (unexpectedly!) raised as important issues in a these tasks. For example, the panning and zooming techniques used in Task 7 (Soccer Ball) were perceived as inappropriate as the camera at one stage 'lost sight' of the ground – an important frame of reference for the viewer observing the shape of the ball's trajectory. Also, the stroboscopic technique used in Task 15 (Cart & Ball) led to an observation dilemma when it was discovered that there was no actual evidence of the ball landing back in the cart. When viewed in step-frame mode, it was apparent that the last 'snapshot' of the ball was actually just before it reached the cart. Consideration of these filming issues is obviously crucial to the future use of the digital video medium in multimedia-supported POE tasks.

Thirdly, the real-life physical settings depicted in the video clips were interesting and relevant for the students and helped them to feel comfortable and confident in voicing their opinions, particularly in the important prediction phase of the POE process. Both teachers acknowledged the ability of the digital video medium to present (and accurately replicate) unusual or time-consuming demonstrations that would be difficult to set up in a classroom. However, a few task settings created a degree of confusion for some students, providing them with excuses after incorrect predictions. These problems highlighted the importance of teacher facilitation to help students acquaint themselves with these rich task settings before making predictions.

From a constructivist perspective, many of the affordances emerging from this part of the study were a major factor in helping students articulate their views with confidence and initiating some of the rich discussions presented in chapter 6. The extra learner control and the affordances of the digital video medium discussed in this section gave students unique opportunities to discuss and reflect on rich scenarios and their related personal science conceptions. These affordances also are related to the probe function of the tasks, providing a greater insight into learners' strongly held beliefs.

9.3 Implications and recommendations for practice

This study has implications for the design and use of multimedia-supported POE tasks to be used as probes of understanding in science education. Recommendations can be made relating to the teacher's role, the design of the tasks and the pedagogy associated with using them. The study also has more general implications for the use of multimedia in science education.

9.3.1 Role of the teacher

Despite the move away from teacher-led demonstrations in this study, the role of the teacher was found to be crucial at different stages of the implementation of these student-centred, computer-mediated POE tasks. Firstly, in terms of probing student understanding, the need for careful teacher observation of student groups emerged as a crucial supplement to the students' written and drawn responses. For example, gestures and off-computer mini experiments gave vital clues as to what students were thinking during their engagement with the tasks. However, the crucial roles of teacher mediation seemed to be at both the prediction and explanation stages. Although great care was exercised with the level of (written) detail given to students about the rich contexts in each task, teacher mediation was necessary in some cases to help students clarify anomalies, become fully acquainted with task settings and hence make confident and accurate predictions. Alternatively, teachers may like to consider introducing the physical setting of each task beforehand in a whole class situation.

As discussed already (refer to section 9.2.1) the explanation phase was not well carried out by students and this was a significant finding in terms of the suitability of the POE strategy for small-group computer environments. Although there were subtle reasons for this outcome in this particular study, it is clear from the literature that this stage of the POE strategy is a difficult one for students. Although further research is needed, there are implications from this study that teachers should perhaps consider completing this challenging phase of the POE tasks as a whole class discussion. Alternatively, other computer-mediated strategies could be carefully considered; for example, students could have access (through a computer network) to other groups' responses to help initiate quality reflections in their explanations (refer to section 9.5.1).

9.3.2 Software design of multimedia-supported POE tasks as probes of understanding

Despite the reported problems with the explanation phase of the tasks, the study clearly revealed the suitability of a multimedia environment for the POE strategy. For example, this environment effectively scaffolded the POE strategy, facilitating small group learning environments and giving students control over the pacing of the tasks. The multimedia setting supported the digital video medium and its significant affordances for the observation process. Future use of the POE strategy should take advantage of these aspects afforded by computer environments.

Findings suggest that video footage of real life contexts should be seriously considered by POE authors and software designers. Indeed, scenarios depicting laboratory-based contexts that are difficult to observe, expensive, dangerous or time-consuming to set up in the classroom also need to be considered. Because animations, simulations and microworlds have more commonly been used for computer-mediated POE tasks (e.g., Tao & Gunstone, 1999a,b), the use of video footage of real-life, mainly out of classroom contexts, was a significant feature of this study. These contexts were motivating for students and often promoted meaningful discussion. However, as discussed previously, these rich contexts need to be carefully explained before students can confidently make predictions. Apart from extra teacher facilitation (see section 9.3.1), this problem of familiarising students with these rich physical settings can be partially solved by using video previews of scenarios that show the first few frames of an event without showing the demonstration outcome. Indeed, this strategy worked well in this present study to help students get a 'feel' for each task setting before making predictions.

Great care is needed in the consideration of film techniques to be used in these tasks. Students can easily become disoriented while observing these clips if inappropriate techniques are used. For example, camera angles, zooming or panning effects may easily affect key frames of reference. Indeed, flash rate settings used in stroboscopic film techniques need to be accurately set to reveal actual evidence of demonstration outcomes.

9.3.3 Pedagogy associated with the use of multimedia-supported POE tasks to probe understanding

The study's findings add to the body of literature endorsing the collaborative use of appropriate computer-mediated tasks. School computer laboratories are usually specifically designed for individual work at the computer and these settings often discourage small group work. Indeed, other instruments used to elicit students' science conceptions (e.g., multiple choice tests and concept maps) are typically used individually. The collaborative use of the POE tasks at the computer in this study was shown to be meaningful and appropriate. Indeed, the use of student pairs worked well and avoided the 'exclusion dimension' experienced by students on the outer edge of larger groups who find themselves stranded and disengaged from the computer-based activities (Roth et al., 1996). The findings in this study would suggest that pairs is an optimum group size for collaboration at the computer for the purpose of probing students' science views and promoting discussion of these views. Indeed, the use of student pairs reduced the total amount of class data (in this case recorded by the computer) needed to be synthesised by the teacher, making the instrument more efficient and convenient for teachers.

Students' frequent use of gestures and in particular their off-computer mini experiments served as a backdrop to many meaningful and creative learning conversations in this study. However, these communicative acts often occurred in a confined physical space around the computer, often using readily available objects such as pencil cases. These findings have rather practical but important implications for computer-learning environments supporting the POE strategy. Rather than performing these significant off-computer activities around a computer's peripherals (keyboard, mouse, etc.), a separate physical space away from the terminals should be provided where students can go to perform these off-computer mini experiments. Increased teacher mediation would be needed in these areas and relevant resources to the given activity (e.g., objects such as balls used in the video clips, rulers, stop watches, etc.) could to be supplied to students. Students in these 'computer-free' zones also could be given access to a video camera (refer to section 9.5.5).

9.3.4 General use of multimedia in science education

There has been much criticism of students' passive use of video (both VHS and digital video) and indeed multimedia programs. For example, the 'butterfly defect' can easily occur when students are lead to "aimless, visually lured wandering through the screens of a hypermedia program" (Salomon & Almog, 1998, p. 235). This thesis argues for a more engaging use of multimedia. The strategy recommended here is for teachers to use appropriate short digital video clips of demonstrations where students are asked to predict outcomes and reflect on their reasons before actually viewing them! This thesis also is endorsing the use of suitable video clips within computer-based multimedia programs in small group settings rather than the typically passive viewing of TV monitors in whole class settings.

9.3.5 Use of this particular program in alternative conceptions research

The program used in this study offers an alternative to student interviews and other traditional diagnostic instruments used by educational researchers to elicit alternative conceptions. The findings from this study, particularly those presented in Chapter 7, suggest that multimedia-supported POE tasks are most appropriate instruments to use when researching alternative conceptions amongst science students. The large variety of relevant and detailed conceptions elicited by the program suggest that the computer-based tasks were most suitable probes of understanding. Indeed, the collaborative use of the instrument should not be overlooked. As students work collaboratively on these tasks, subsequent discussions potentially provide insightful data to supplement recorded text responses to the POE task. Indeed, the effective use of in-built computer microphones and voice recognition software to record students' conversations at the computer should be possible in the near future.

9.3.6 Use of this particular program in physics education

The POE tasks used in this study offer a high level, meaningful assessment tool to physics educators. Senior high school physics continues to be seen typically as a challenging subject and indeed research continues to show that students complete courses with poor conceptual understanding. Rote learning is unfortunately a common process and low level assessment tasks act as catalysts for these practices! Indeed, enrolments in introductory physics courses are in decline around the world (Gunstone, McKittrick, & Mulhall, 1998). This study provides an example of technology-mediated authentic learning in the domain of physics and hence adds to the body of literature that suggest possible solutions to these concerning trends. The design of the computer-based instrument used in the study was informed by the literature on alternative conceptions and the history of science. Although they were used to elicit pre-instructional conceptions, the POE computer tasks also could be used in other ways either as formative or summative assessment tasks (refer to section 9.5.3). Hence, the findings from the study have implications for meaningful learning in physics.

9.4 Limitations

A number of unrelated issues were not explored in this study due to time constraints and these do represent possible limitations. These included various socio-cultural issues, some peer learning outcomes and an exploration of sources of students' alternative conceptions. There also were a few technical difficulties that represented minor limitations in the study.

Socio-cultural influences such as school culture and the socio-economic or ethnic background of students were not considered in the results of this study. The two schools in this study were chosen because of the interest expressed from the teachers of the classes used in the study. Coincidentally, both schools were among the more prestigious private schools in the Sydney area. However, associated influences from these school cultures were not accounted for in this study.

The researcher collected anecdotal evidence of students learning to 'talk science' and developing their science discourse skills during the study. (Indeed, this was a planned learning outcome of the program!) Unfortunately the time constraints of the study limited any reports of these observations. Although this represents a limitation on this study, this particular issue will be a focus of future investigations (refer to section 9.5.1).

Many alternative conceptions were elicited from the students' engagement with the program as identified in chapter 7. However, this discussion is essentially based on the researcher's own conceptions of the students' conceptions (refer to section 5.7.1), representing a limitation to this section of the study. Another limitation was the lack of discussion about possible sources of these alternative conceptions. There were minor attempts to discuss the source of some significant alternative conceptions (e.g., refer to section 7.2.2 for a discussion of the students' use of the term *momentum* to imply impetus). However, the study was not designed as an alternative conceptions study and other interests limited any discussion of these sources. Further longitudinal studies in this area could investigate this issue.

There were naturally some technical limitations during the study. The window size of the digital video clips was approximately 40% of the whole screen—the limit of the technology at the time of program development. Screen resolution also was an issue with a few clips. For example, the resolution of Task 9 (The Astronaut) was quite poor. However, the clip was included in the program as the context of the video was considered highly desirable and the outcome of the demonstration was just visible. Future developments in this technology (e.g., increases in the standard window size of digital video clips, better quality resolutions, ability to zoom, etc.) will only enhance the observation process. Fortunately, only one group out of both classes experienced some technical problems with their computer. This particular group (from the Year 11 class) was using a laptop and it 'froze' on them twice. However, minimal time was lost and the students coped well with this unexpected delay.

9.5 Directions for future research

There is a need for further exploration and justification of computer-mediated POE tasks as legitimate probes of understanding in science education. There are many issues relating to the design and use of the tasks used in this study that warrant further investigation. Some represent further extensions of various findings from the study while others are new but important issues waiting to be explored. Future research in this field should provide further insights into the innovative use of the POE strategy in a computer environment.

9.5.1 *Further exploration of learning outcomes associated with the POE computer tasks*

The constraints of this study restricted the full investigation of all learning outcomes associated with the program. Future research should further investigate issues associated with peer learning and affective outcomes.

This study used a social constructivist perspective to focus on important learning outcomes resulting from peer interactions. Future investigations could explore possible ways for students to communicate between groups and reflect on other groups' beliefs (as well as their partner's views). For example, if all groups posted their responses on a central database accessible through a network, they could establish a 'discourse community', comparing and reflecting on the multiple perspectives of others (e.g., see Lin et al., 1999). Indeed, this process could help students to engage more meaningfully in the challenging explanation phase of the POE strategy.

The program used in this study provided students with an opportunity to engage in 'science talk' (Lemke, 1990) and a means of developing science discourse skills (exploration, justification, negotiation, challenge, etc.). There is a need for further analysis of students' conversations (and indeed their writing) to explore students' development of these skills and their ability to use the 'canon of science'. This research could explore the use of computer-based POE tasks to identify the "discursive changes such as to transform their everyday discourse into more canonical discourse" (Roth et al., 1996, p. 1013).

Affective learning outcomes of the program also could be explored further. The challenging, real-world contexts presented in the program were designed to stimulate students' intrinsic interest and curiosity in various physics events and related principles. The program also was designed to foster student awareness and appreciation of the integral relationship between physics and students' everyday lives. Further qualitative insights into these developments would be most valuable, especially for low ability or 'at risk' students.

9.5.2 Longer-term 'effects of' the computer-based POE tasks

Salomon et al. (1991) discussed two types of effects relating to technology-mediated learning. The effects *with* the technology refers to the effects attained during the 'partnership' with the tool and the effects *of* the technology refer to the more lasting effects (or 'cognitive residue') as a consequence of students' 'mindful engagement' with the tool. Clearly this thesis has focused on effects *with* the computer-mediated POE tasks. Future research could possibly investigate the genuine transfer of learning from this environment to other tasks (i.e., effects *of* the technology). For example, does the students' use of these POE tasks affect their value of the POE strategy overall? Does it help them to engage more skilfully in non-computer based POE tasks or indeed in other collaborative learning tasks? Are certain peer learning skills (negotiation, conflict resolution, etc.) developed through their use of these computer-based tasks? Are their general observation skills developed? Is their attitude to the process of observation improved? Indeed, do the tasks affect their attitude to the relevant subject matter?

9.5.3 Pedagogical issues associated with computer-mediated POE tasks

There are many situations where 'live', teacher-led POE tasks are pedagogically sound and small group POE tasks can easily proceed in a non-computer environment. The recommendation from this study is that suitable demonstrations such as dangerous, expensive, time-consuming or difficult scenarios should be filmed and placed into multimedia formatted POE tasks when possible. This recommendation also would cover some laboratory-based scenarios that could be more effectively observed using film techniques available through the video medium (e.g., viewing falling objects using the step-frame facility). However, like most technology-mediated learning tasks, teachers need to discern when these types of tasks are appropriate and how they should be used. For example, when should a teacher choose to conduct whole class, small group or individual POE tasks with or without a multimedia-supported environment? Indeed, in terms of eliciting students' science conceptions, when are these types of tasks appropriate and when are other instruments such as computer-mediated concept maps suitable? These types of important pedagogical questions need further exploration. Indeed, technology innovations could affect the answers to these questions. For example, flat, horizontal computer screens (otherwise known as 'e-tables' or 'digidesks') could well reduce the exclusion zone around a screen, increasing the optimum group size for computer-mediated POE tasks.

The POE tasks used in this study can be used for purposes other than pre-instructional probes of understanding. For example, they could be used as a summative assessment tool or indeed as a tool to initiate conceptual change—perhaps in conjunction with post-session remediation and other conceptual change strategies (e.g., see Searle, 1993). These alternative uses of computer-mediated POE tasks also are important and need further attention.

9.5.4 Further affordances of the computer environment for the POE strategy

Although the computer environment was shown to be most suitable for the POE strategy in this study, there were some technologies that were not considered and could be further investigated. These include the use of a supplementary 'page' in the software to allow students to indicate their level of commitment to their predictions; the use of a drawing or paint program to allow students to create and save their digital drawings and the further innovative use of appropriate multimedia resources.

Dawson and Rowell (1995) discuss a supplementary step in electronic multiple choice items that can give some indication of the level of uncertainty in participants' responses. This effectively involves students going to a separate screen after making their multiple choice prediction and clicking on one of a number of options that indicate a student's level of commitment to their chosen prediction. In the case of POE tasks used in pairs, students could complete this individually to give extra feedback to the teacher by giving some indication of the mutuality of a response. Investigations into the use of this supplementary technology as part of computer-based POE tasks could be most fruitful.

The ability of students to easily edit their predictions and reasons was a crucial part of the program used in this study. Indeed, the student control over the pacing of the POE tasks gave students greater time to make these editions and many critical incidents occurred as students edited their (written and drawn) responses. The open-ended nature of the drawing responses in particular seemed to promote meaningful discussion and a great variety of elicited ideas amongst students in this study. Further affordances of the computer-mediated environment for these purposes need to be explored. For example, the use of 'e-drawings' using a paint program may well benefit students' drawings. Would these electronic drawings still act as meaningful focus for the students' learning conversation? Would they allow for improved flexibility in the editing of drawings, thereby facilitating quality reflections? Indeed, groupware technologies may be beneficial for these e-drawings. For example, students could use multiple input devices such as electronic pens and 'telepointers' (Cockburn & Greenberg, 1995) to edit and talk about a shared drawing (depicted and updated dynamically—possibly on separate screens). In this way, students collaborate *through* their networked computers. These and other appropriate groupware technologies need to be fully investigated to find their suitability for POE tasks.

Affordances relating to new developments in the field of multimedia also need to be investigated. For example, digital scent (or 'digiscent') technology is emerging as a legitimate media in computer environments. How can this media be used in POE tasks to enhance learning? What topics would be suitable and what particular new strategies would need to be considered? Indeed, how can the sound medium be used innovatively in these multimedia-supported POE tasks?

9.5.5 Further use of the interactive digital video medium

There are numerous unexplored issues relating to the use of the digital video medium to present demonstrations as stimuli for the POE tasks. Technical developments with this medium need to be fully explored for different domains of science and the level of credibility of the medium needs further investigation. Learner-shot video provides an interesting extension of this area of research.

There is a need to further explore the affordances of the digital video medium for different domains of science. For example, what video tools and film techniques are suitable for various science topics? (e.g., In what areas of chemistry and biology can time-lapse photography be used?) Are there any issues to be confronted when using such techniques as part of POE demonstrations? Another example is Apple© Computer's QuickTime© (or cubic) VR technology that enables objects in a photo to be selected and rotated. Users also can zoom and pan around given viewpoints through the use of 360-degree cylindrical panoramic images. What are the affordances and constraints of such an exciting development for the POE strategy? Do they give learners extra control over the observation process?

The credibility of the digital video medium for these types of tasks is quite an urgent line of research in this field. Although this study touched on this subject, important questions need to be asked about the level of belief in these video clips. For example, Roth (1996) found that microworlds can be "ontologically ambiguous and subject to interpretive flexibility" (p. 185/6). Are the digital video clips used in this study also 'ontologically ambiguous'? As students become more computer literate and familiar with video editing software, how will this affect their perceptions of the video medium as representations of reality? Indeed, how do students perceive the credibility and authenticity of animation and simulations when used in POE computer tasks? Do they really link these representations with the real world?

An interesting development that confronts this issue of film credibility is the use of teacher and student-shot film clips. Learner-shot video laboratories (Squires, 1999) can potentially give students ownership of these video clips and perhaps enhance the authenticity of related learning experiences. For example, Tasks 1 and 2 from this study (Falling Ball & Rising Ball) could easily be filmed by students for consideration in a POE task. The effect of students (and indeed teachers) filming their own scenarios needs further investigation. For example, does it improve the level of credibility of the task demonstrations?

9.5.6 Software design issues

The specific design of the program used in this study could be further researched and developed in the future. Immediate concerns include the contexts used in the tasks, the general structure of the program and the method used by the program to code and record students' responses.

There were comments from some students that the use of ball contexts was slightly excessive and hence a greater variety of contexts could be desirable. Some students also found the tasks to be somewhat repetitive. Judy mentioned in her interview that students do not fully appreciate the design of these types of software due to their lack of awareness of their own alternative conceptions. For example, Tasks, 10 and 11 were similar tasks and probably appeared a little repetitive to students. However, there were subtle mass variations between the two contexts and some students' impetus beliefs were exposed through these variations. This aspect of students' perceptions needs to be considered when evaluating software; however, further development in this area of the program is certainly warranted.

The linear structure of the program was really a partial solution to the problem of students observing outcomes of tasks that could affect subsequent task predictions. Guidelines for the development of constructivist software encourages a low structure non-linear sequencing and a high degree of student access to material, providing students with many navigational opportunities (Kennedy & McNaught, 1997). Exactly how this could be achieved, without jeopardising the probe function of the tasks, needs further investigation.

The computer-based system used to record and report students' views and responses to the teacher also could be developed to become more teacher-friendly. For example, more advanced, automatic coding of students' recorded alternative conceptions, especially those matching known alternative conceptions emerging from the multiple choice options, could help teachers synthesise class responses more efficiently. As discussed previously, future versions of the program could permit students to make and submit electronic versions of their drawings, saving and filing them with related text responses.

9.6 Conclusion

Understanding science involves developing and refining ideas about science phenomena into an integrated perspective. This process requires analysing, linking, testing and reflecting on scientific ideas (Linn, 1998). The research reported in this thesis provided an illustration of how technology can mediate this learning process. As well as acting as an efficient and convenient teaching instrument to elicit students' pre-instructional conceptions, the POE computer tasks facilitated reflective peer conversations and took advantage of new affordances offered by the multimedia nature of the program. In this way, the study explored significant developments in the use of the POE strategy in science education. The findings have implications for the meaningful engagement of science learners as they strive to comprehend and fully appreciate their physical universe.

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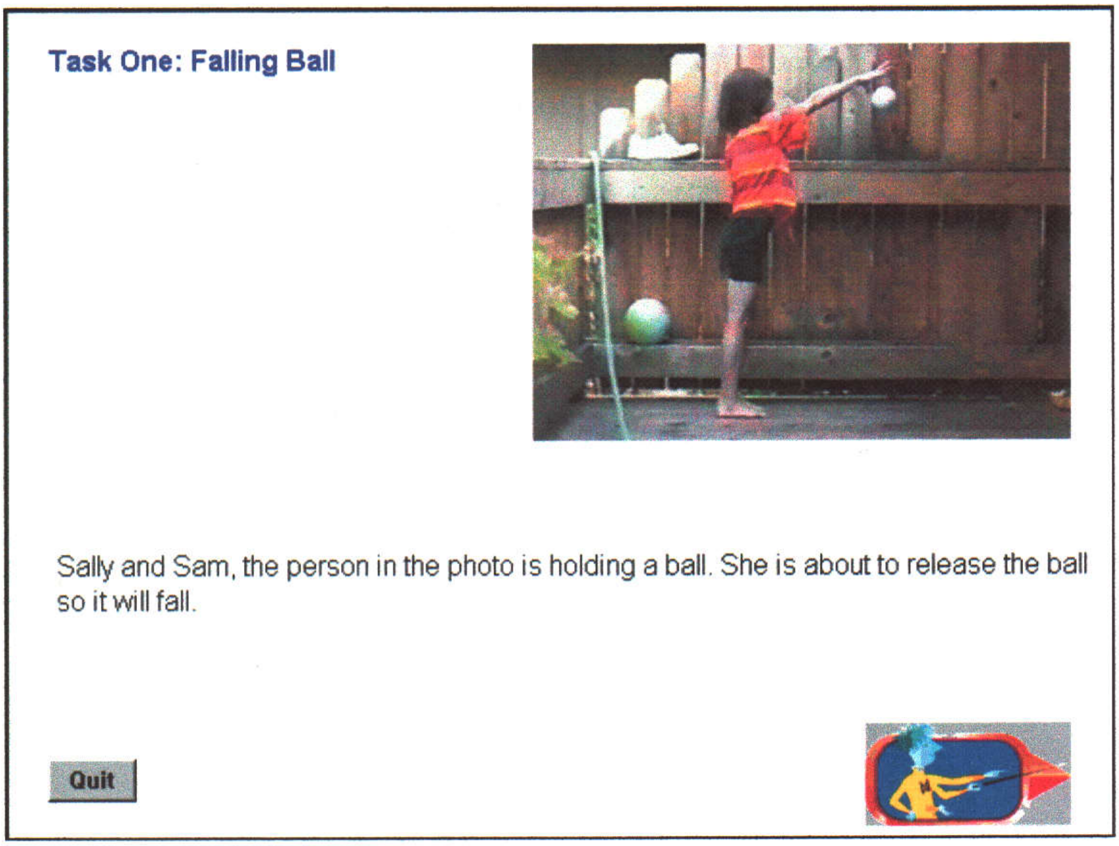
APPENDIX A

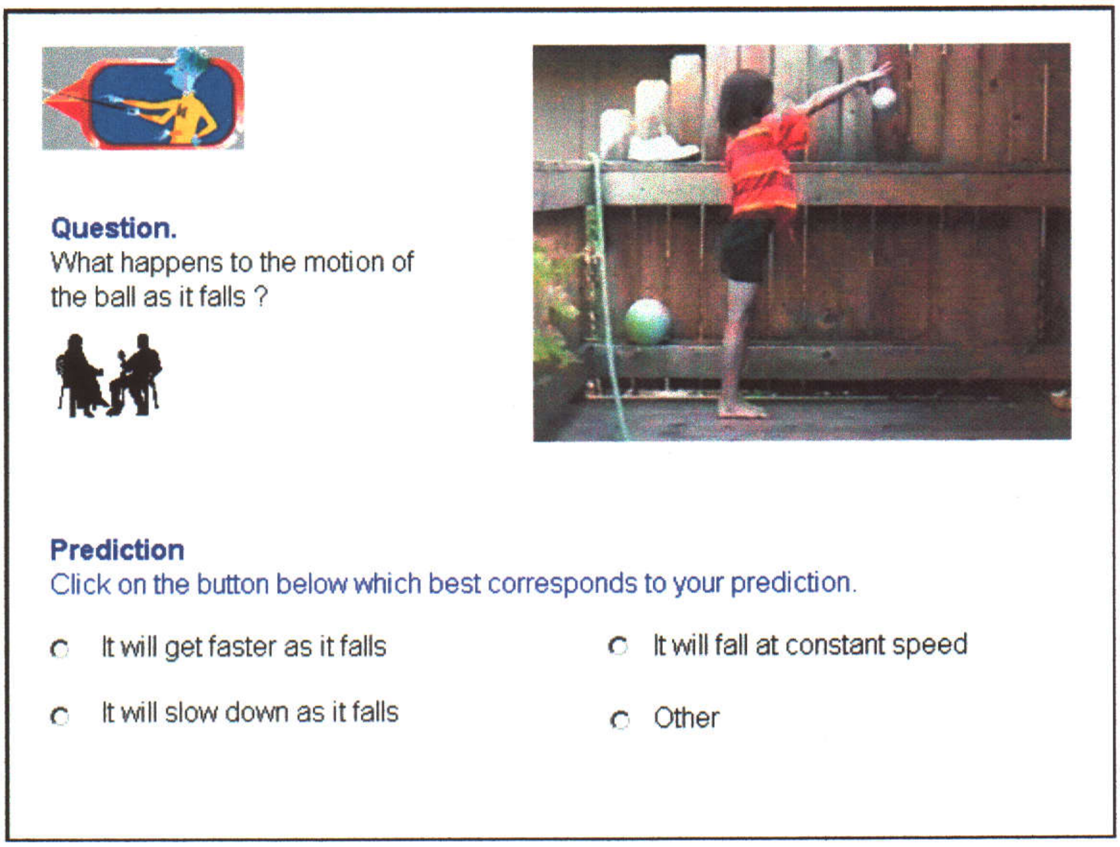
OPENING 2 SCREEN SHOTS FROM TASKS 1 TO 16

The following pages give the screen shot of the first 2 screens from each task in the program. Please note that this only covers the introduction and prediction stages of each task. There reasoning, observation and explanation stage of each task are not shown here. Refer to section 4.2.9 for the screen shots of the full screen sequence of task 12.



Task One: Falling Ball

Sally and Sam, the person in the photo is holding a ball. She is about to release the ball so it will fall.



Question.
What happens to the motion of the ball as it falls ?

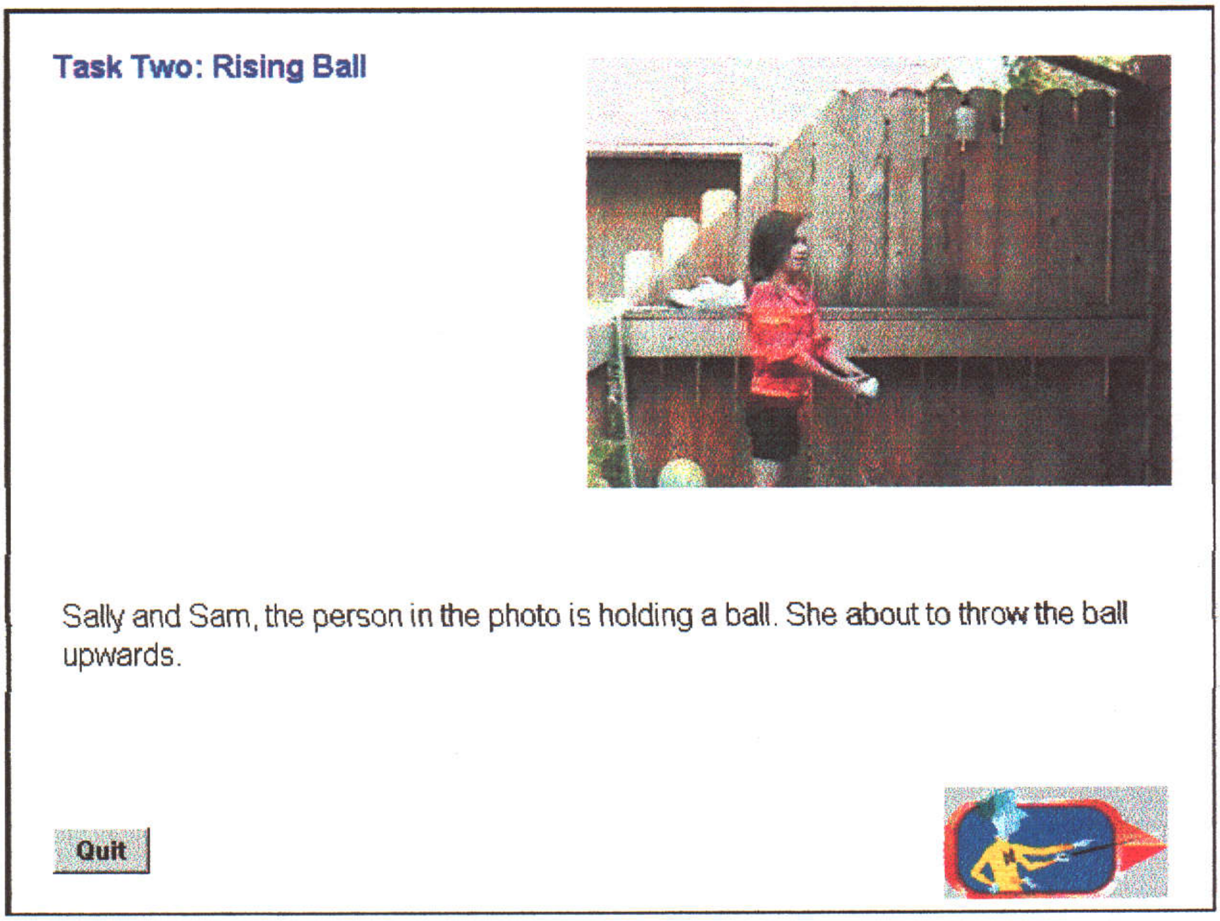
Prediction
Click on the button below which best corresponds to your prediction.

○ It will get faster as it falls

○ It will fall at constant speed

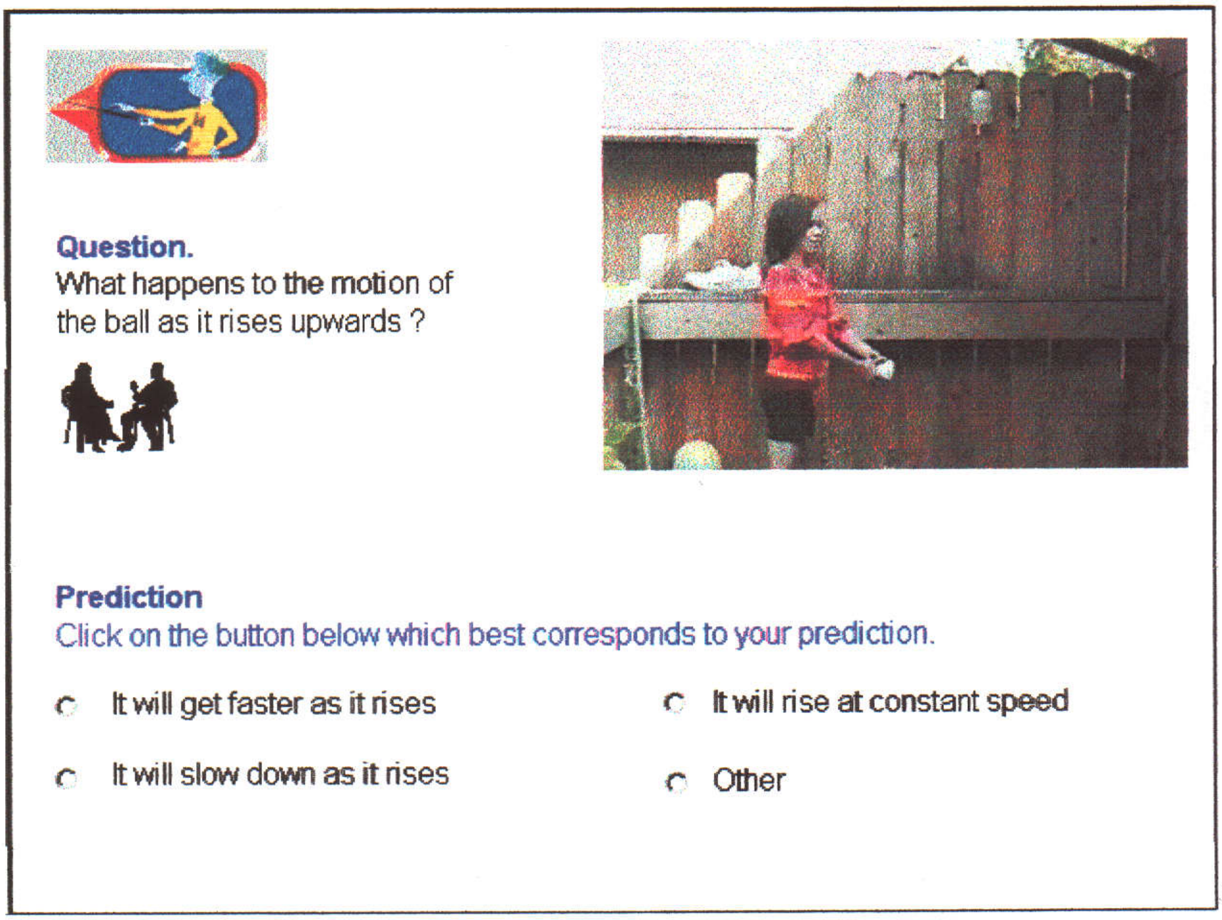
○ It will slow down as it falls

○ Other



Task Two: Rising Ball

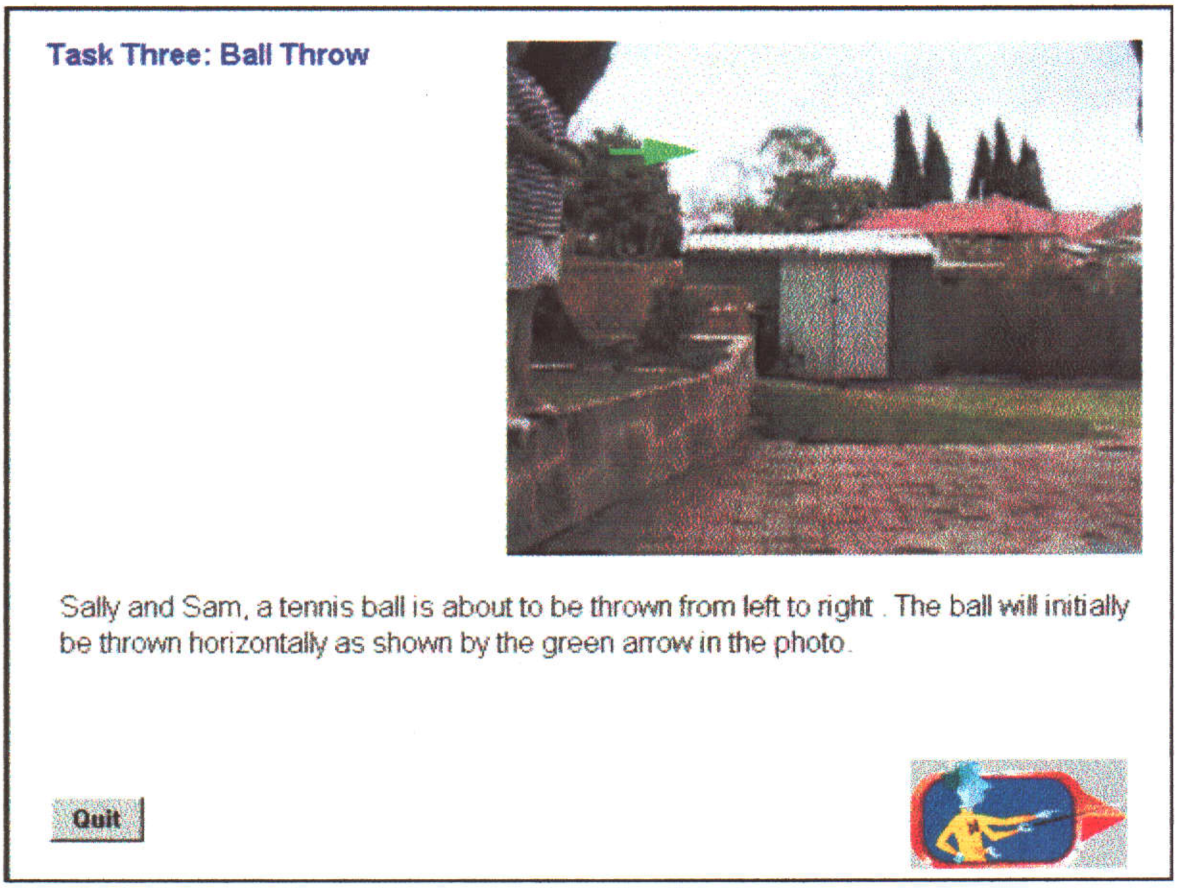
Sally and Sam, the person in the photo is holding a ball. She about to throw the ball upwards.



Question.
What happens to the motion of the ball as it rises upwards ?

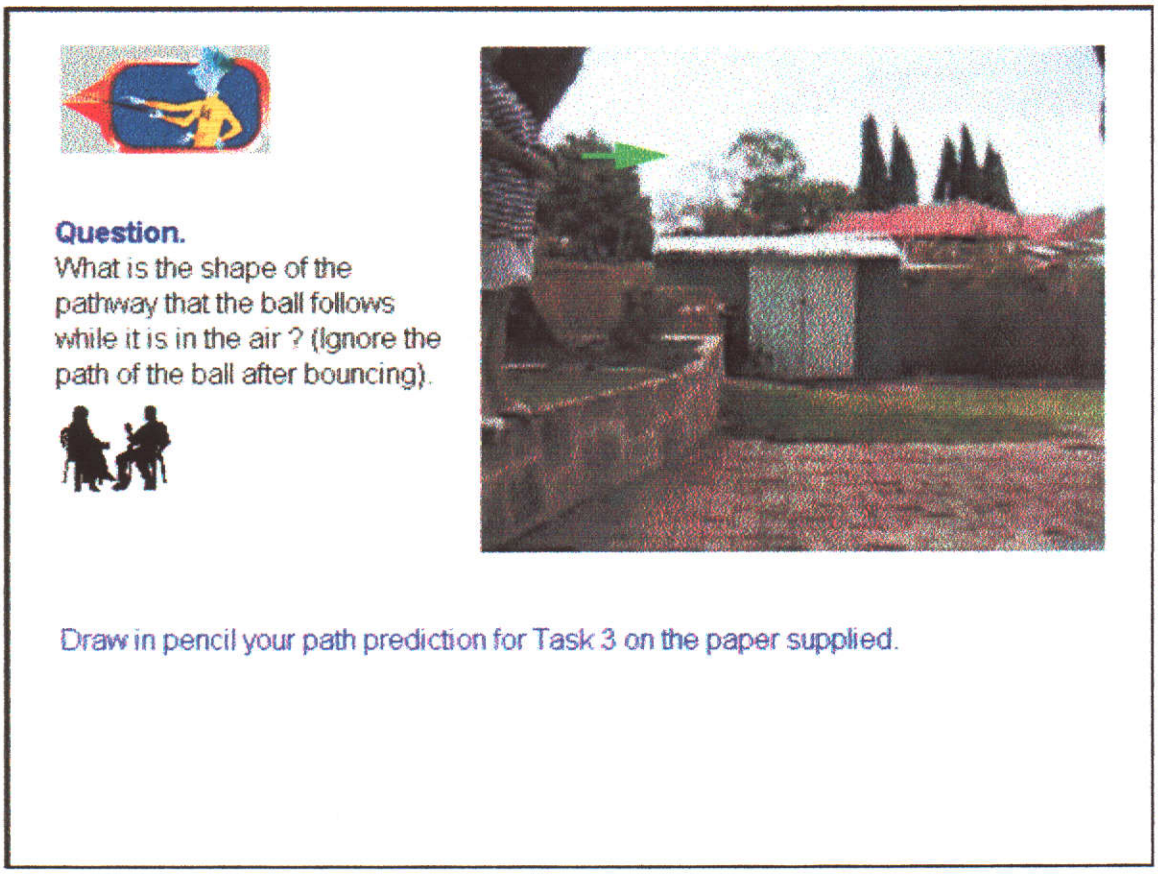
Prediction
Click on the button below which best corresponds to your prediction.

- ○ It will get faster as it rises
- ○ It will slow down as it rises
- ○ It will rise at constant speed
- ○ Other



Task Three: Ball Throw

Sally and Sam, a tennis ball is about to be thrown from left to right . The ball will initially be thrown horizontally as shown by the green arrow in the photo.



Question.
What is the shape of the pathway that the ball follows while it is in the air ? (Ignore the path of the ball after bouncing).

Draw in pencil your path prediction for Task 3 on the paper supplied.

Task Four: Slow Ball Jump

0, a tennis ball is about to roll off the table shown in the photo above. The ball is travelling SLOWLY from left to right in the direction shown by the arrow.

Question.
What is the shape of the pathway that the SLOW ball follows while it is in the air? (Ignore motion of the ball after bouncing).

Draw in pencil your path prediction for Task 4 on the paper supplied.

Task Five: Fast Ball Jump

0, a tennis ball is about to roll off the table shown in the photo above. The ball is travelling FAST from left to right in the direction shown by the arrow.

Question.

What is the shape of the pathway that the FAST ball follows while it is in the air?

Draw in pencil your predicted pathway for Task 5 on the paper supplied.

Task Six: Car Jump

0, the HEAVY car in the photo is about to be driven off the "cliff" while travelling quite fast.
It is travelling from right to left in the direction of the arrow shown. The cliff is approximately 20m high.

Question.
What is the shape of the pathway that the HEAVY car follows while it is in the air?

Draw in pencil your predicted pathway for Task 6 on the paper supplied.

Task Seven: Soccer Ball

0, the soccer ball in the photo is about to be kicked "downfield" (from left to right on your screen) by a soccer player.
The ball will travel through the air (not along the ground).

Question.
What is the shape of the pathway that the ball follows while it is in the air?

Draw in pencil your predicted pathway for Task 7 on the paper supplied.

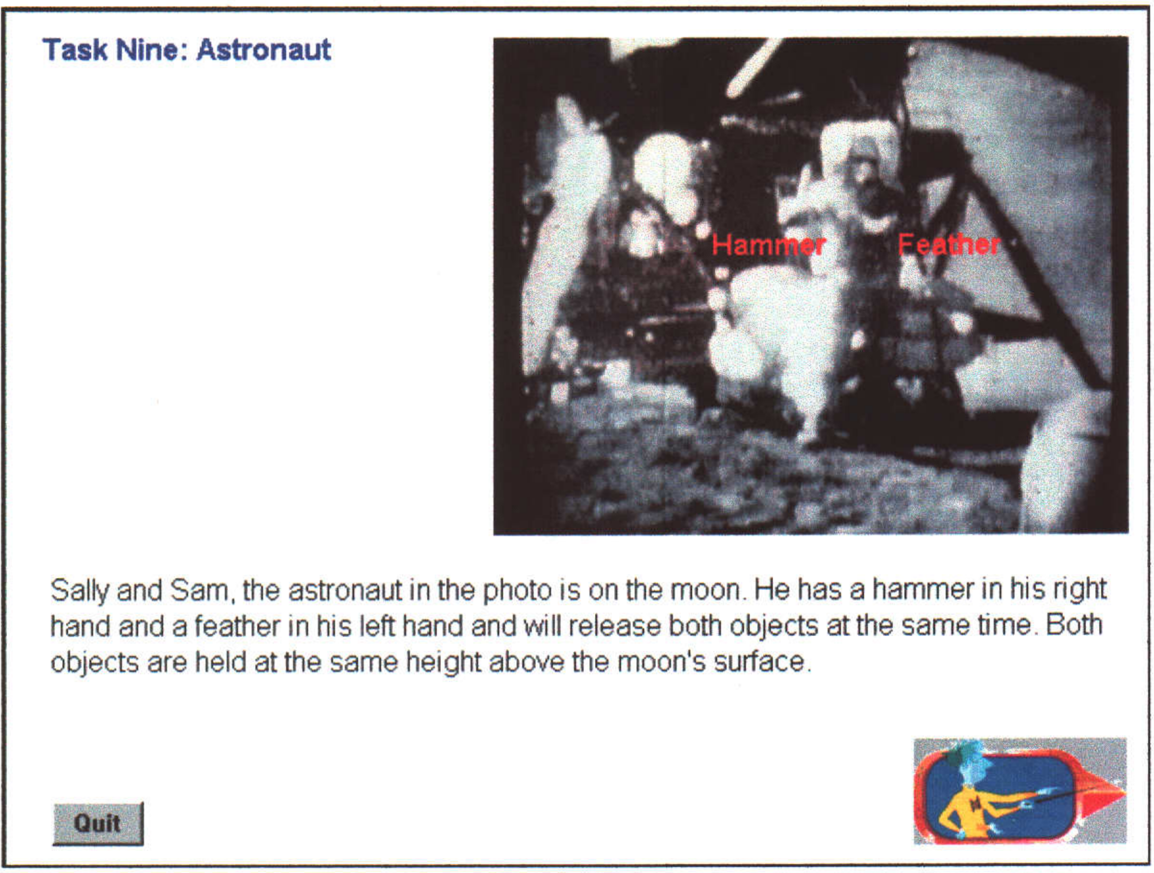
Task Eight: Ball and Swing

0, the person in the photo is riding on a swing. He is holding a tennis ball in his hand. He is photographed here at the maximum height of the his swing. On the next swing forward, the boy will release the ball (while continuing to ride on the swing) at the point marked "X" , just BEFORE he reaches his maximum height.

Question.

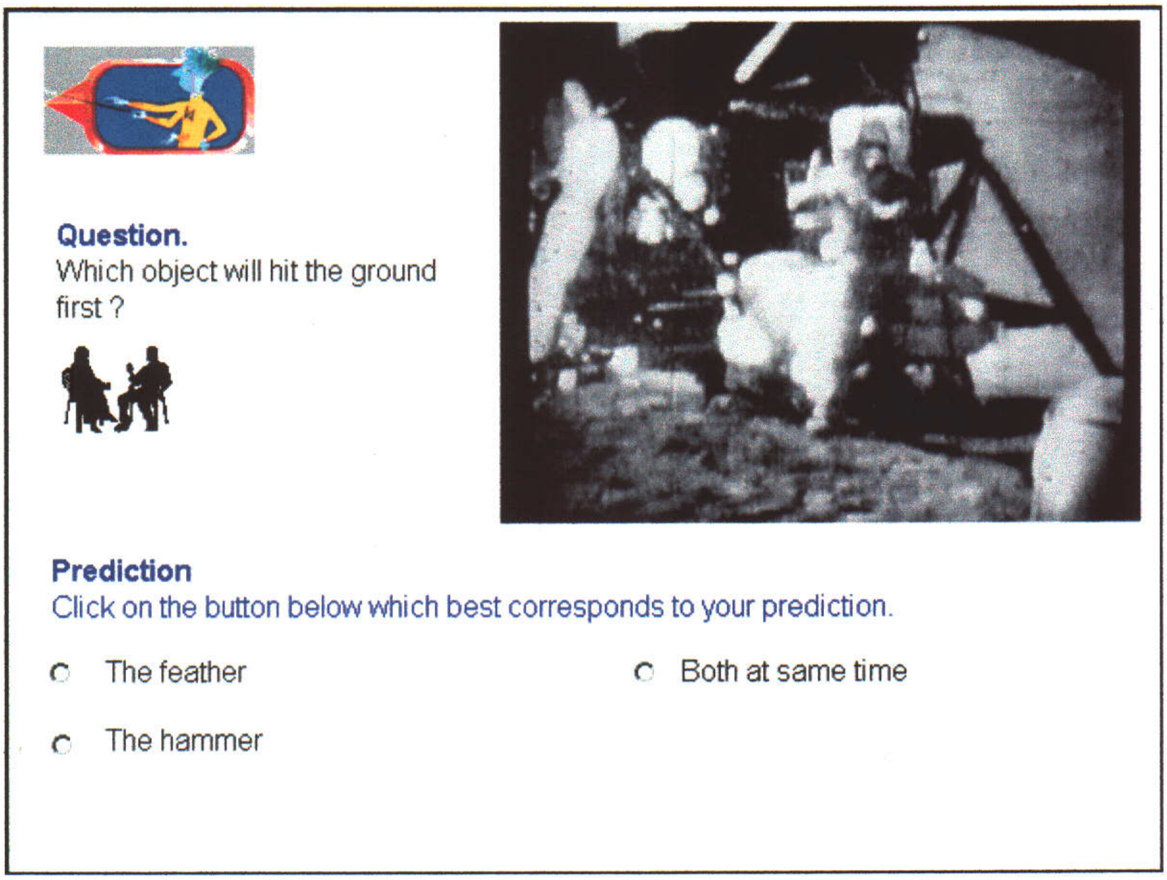
What is the shape of the pathway that the ball follows while it is in the air (after the boy releases it) ?

Draw in pencil your pathway prediction for Task 8 on the paper supplied.



Task Nine: Astronaut

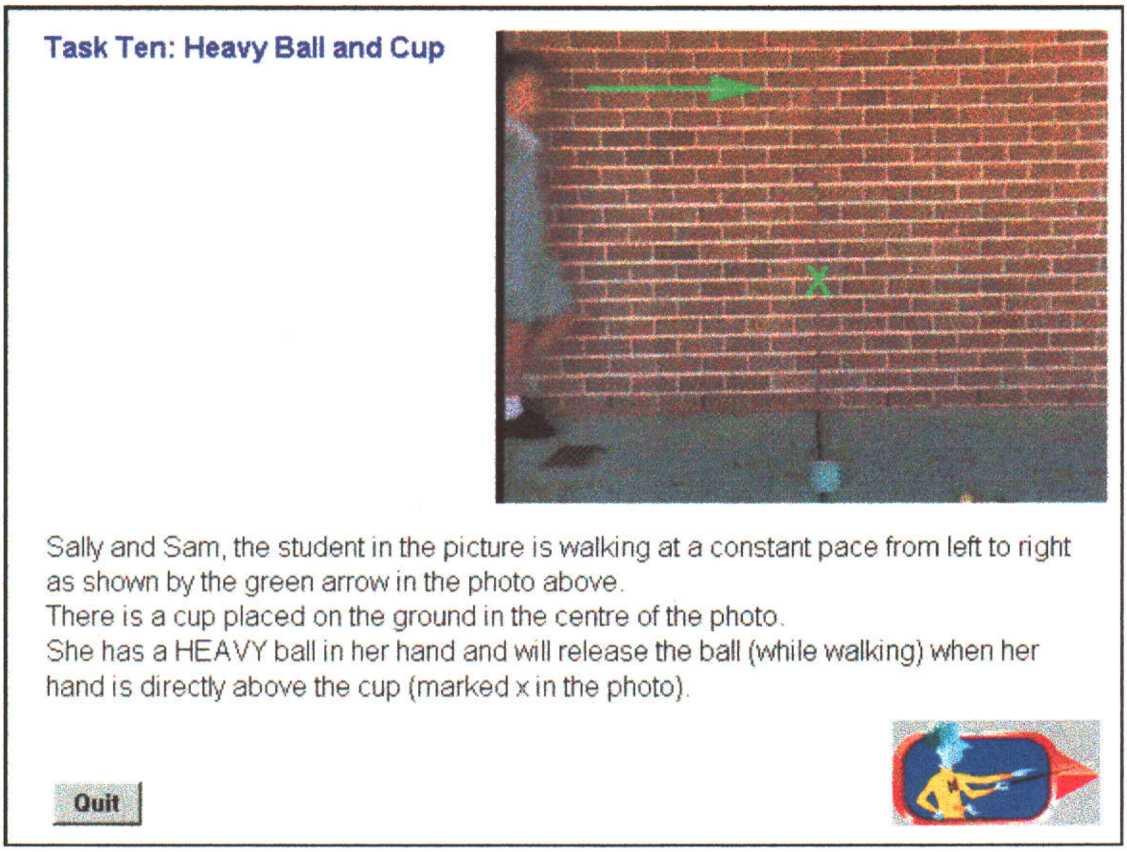
Sally and Sam, the astronaut in the photo is on the moon. He has a hammer in his right hand and a feather in his left hand and will release both objects at the same time. Both objects are held at the same height above the moon's surface.



Question.
Which object will hit the ground first ?

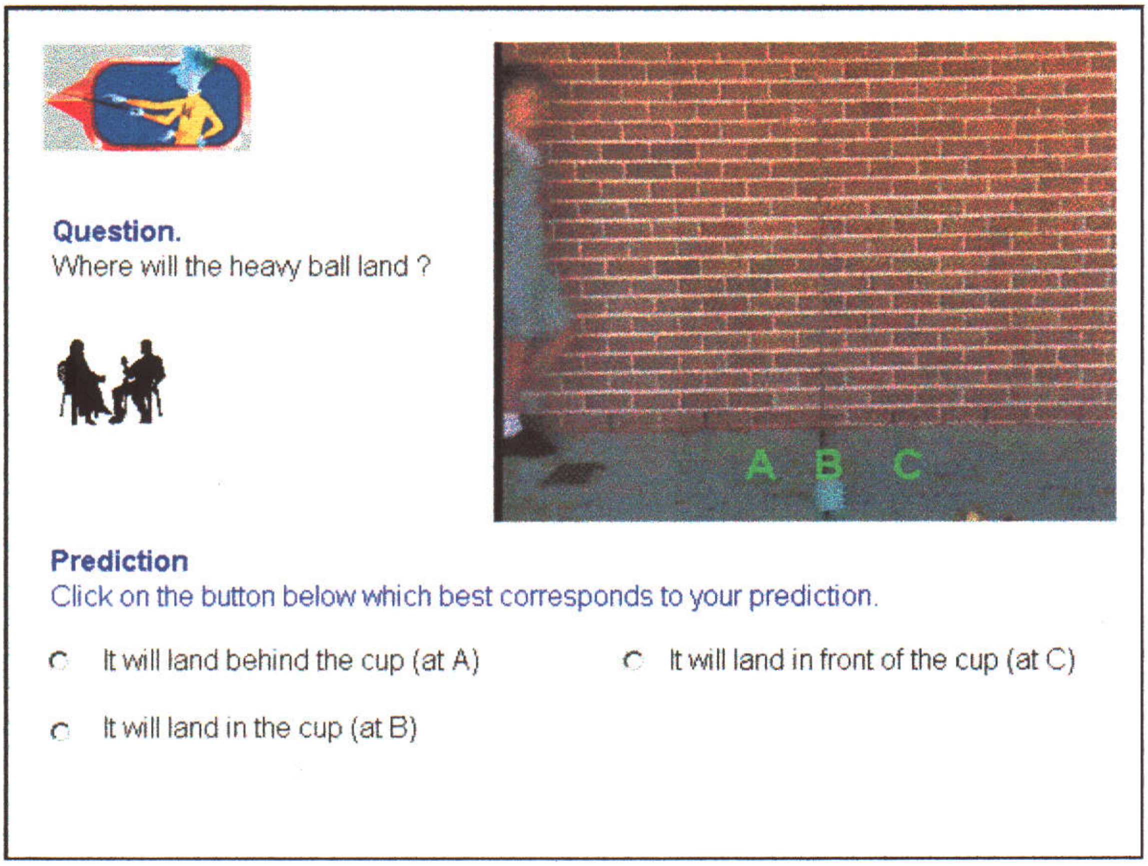
Prediction
Click on the button below which best corresponds to your prediction.

○ The feather
○ Both at same time
○ The hammer



Task Ten: Heavy Ball and Cup

Sally and Sam, the student in the picture is walking at a constant pace from left to right as shown by the green arrow in the photo above.
There is a cup placed on the ground in the centre of the photo.
She has a HEAVY ball in her hand and will release the ball (while walking) when her hand is directly above the cup (marked x in the photo).



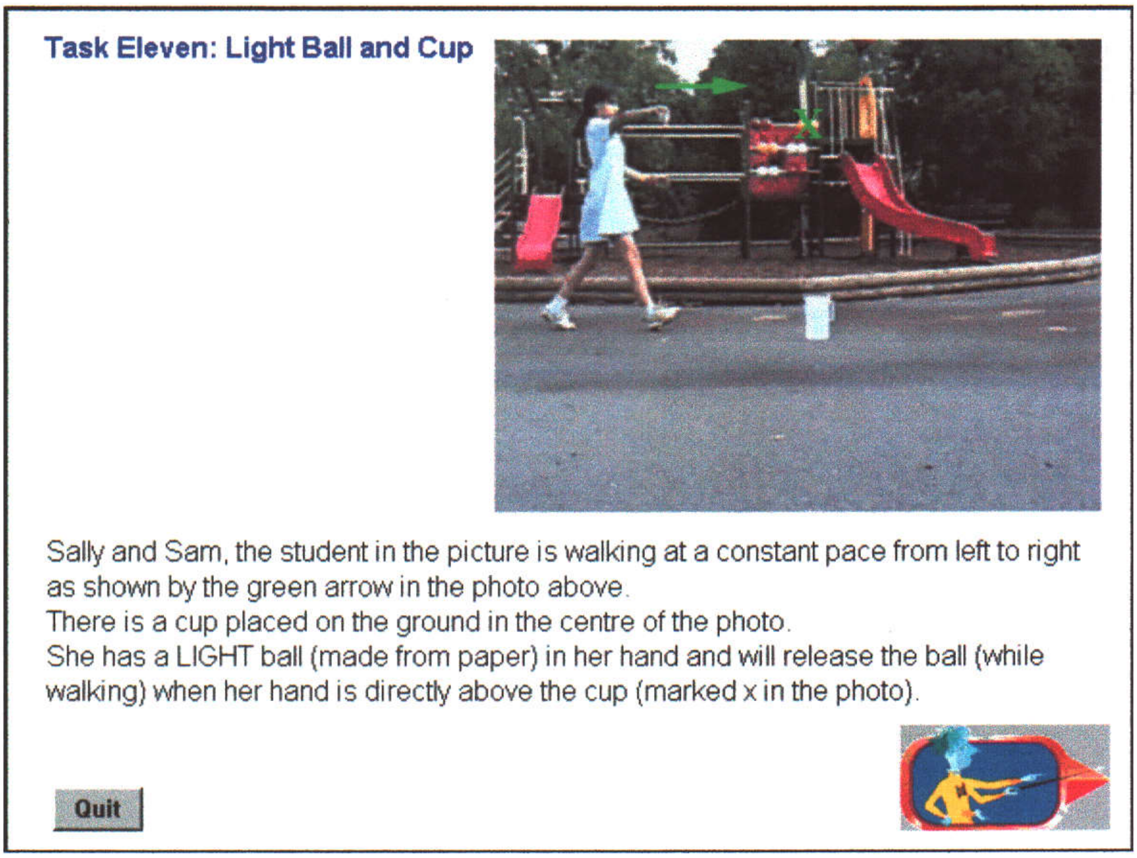
Question.
Where will the heavy ball land ?

Prediction
Click on the button below which best corresponds to your prediction.

○ It will land behind the cup (at A)

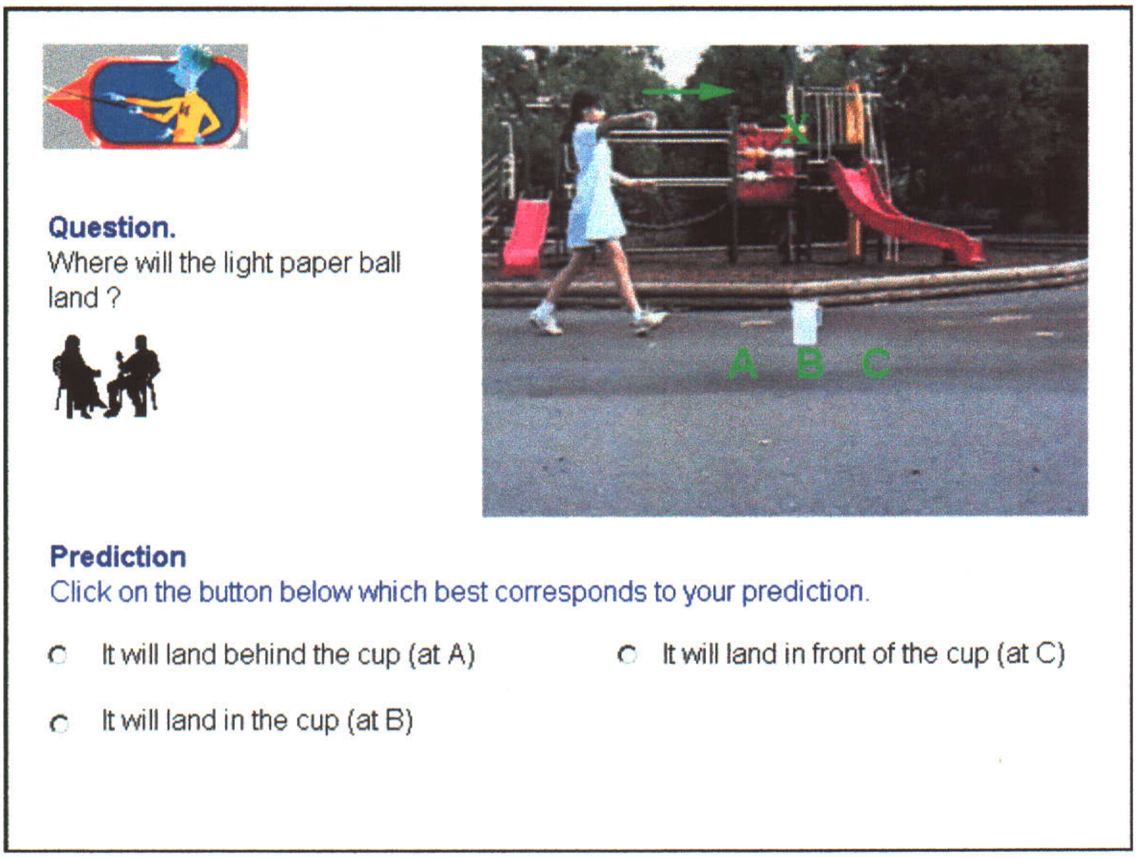
○ It will land in front of the cup (at C)

○ It will land in the cup (at B)



Task Eleven: Light Ball and Cup

Sally and Sam, the student in the picture is walking at a constant pace from left to right as shown by the green arrow in the photo above.
There is a cup placed on the ground in the centre of the photo.
She has a LIGHT ball (made from paper) in her hand and will release the ball (while walking) when her hand is directly above the cup (marked x in the photo).



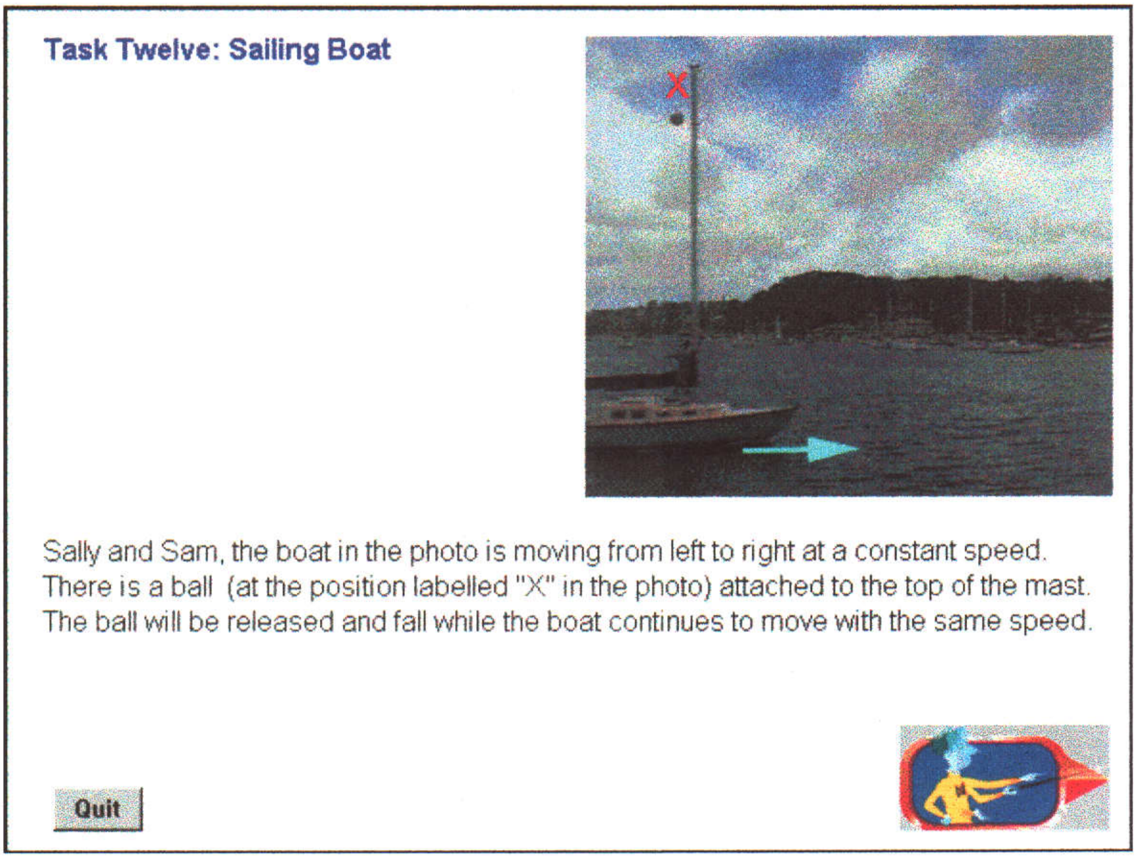
Question.
Where will the light paper ball land ?

Prediction
Click on the button below which best corresponds to your prediction.

○ It will land behind the cup (at A)

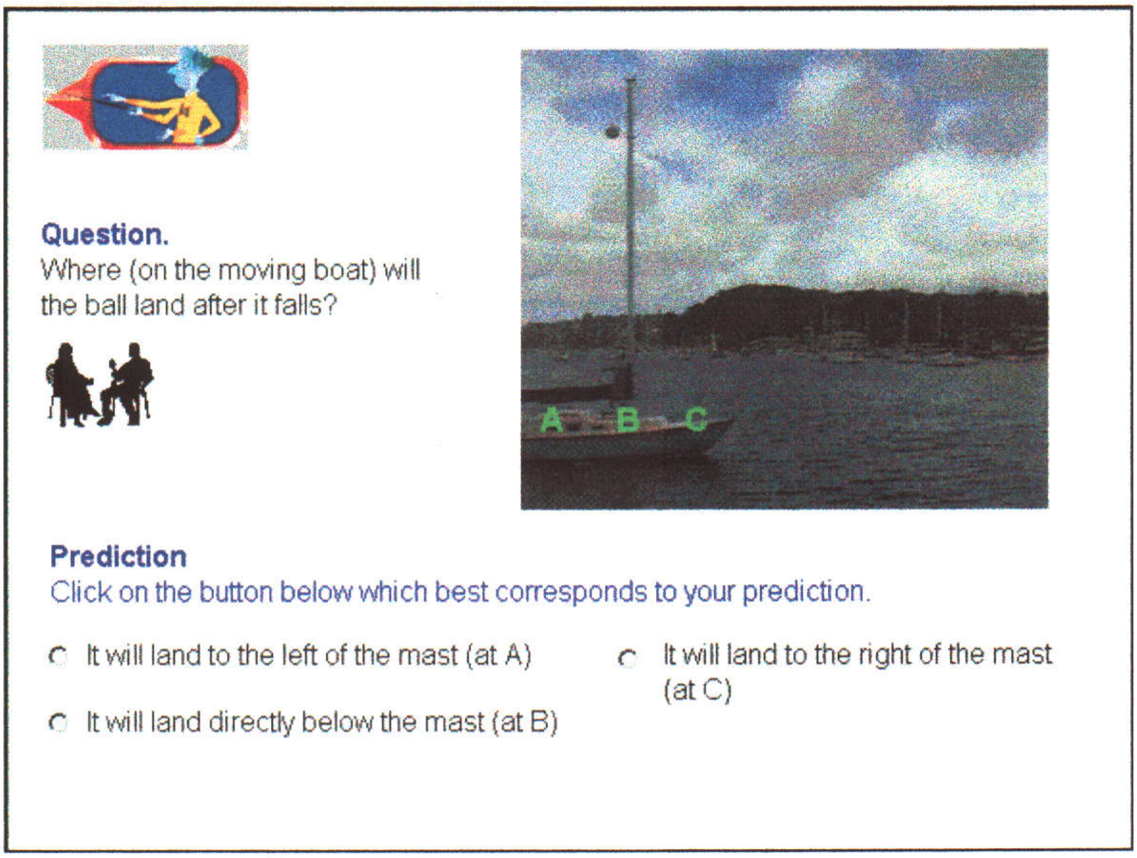
○ It will land in front of the cup (at C)

○ It will land in the cup (at B)



Task Twelve: Sailing Boat

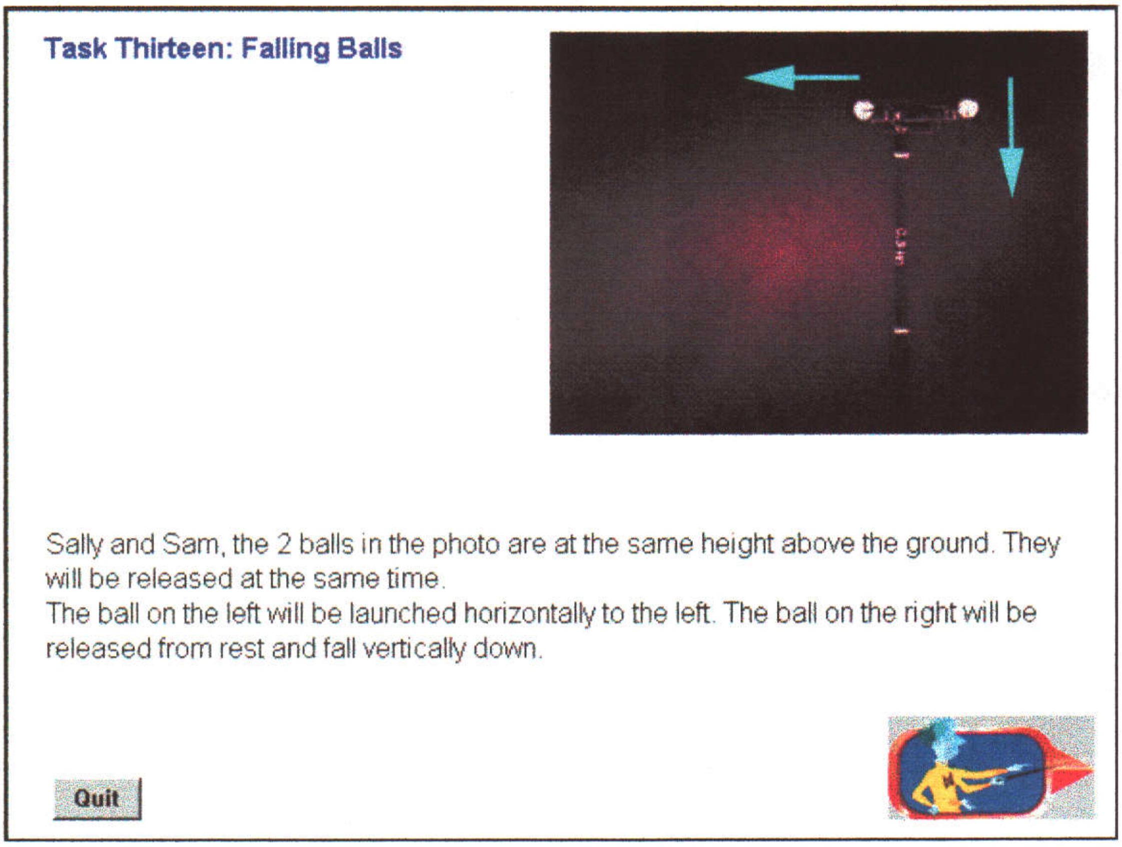
Sally and Sam, the boat in the photo is moving from left to right at a constant speed. There is a ball (at the position labelled "X" in the photo) attached to the top of the mast. The ball will be released and fall while the boat continues to move with the same speed.



Question.
Where (on the moving boat) will the ball land after it falls?

Prediction
Click on the button below which best corresponds to your prediction.

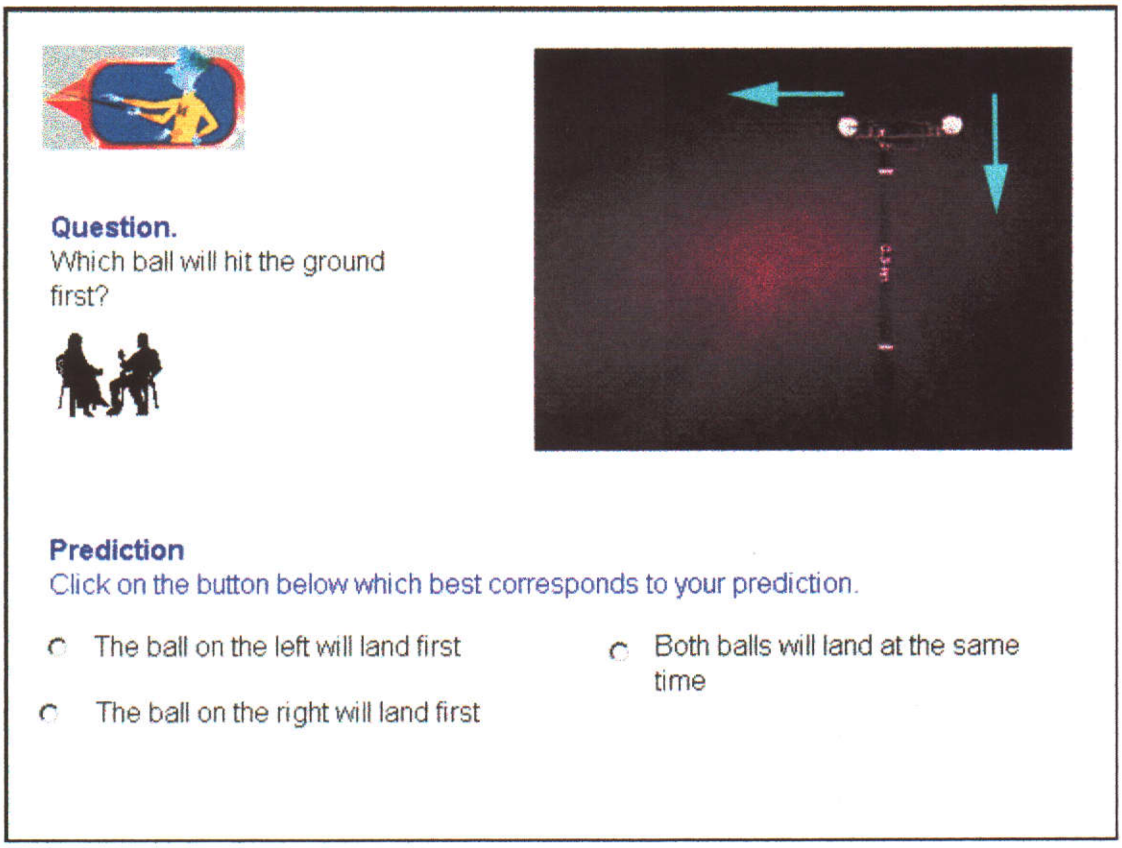
- ○ It will land to the left of the mast (at A)
- ○ It will land directly below the mast (at B)
- ○ It will land to the right of the mast (at C)



Task Thirteen: Falling Balls

Sally and Sam, the 2 balls in the photo are at the same height above the ground. They will be released at the same time.

The ball on the left will be launched horizontally to the left. The ball on the right will be released from rest and fall vertically down.



Question.

Which ball will hit the ground first?

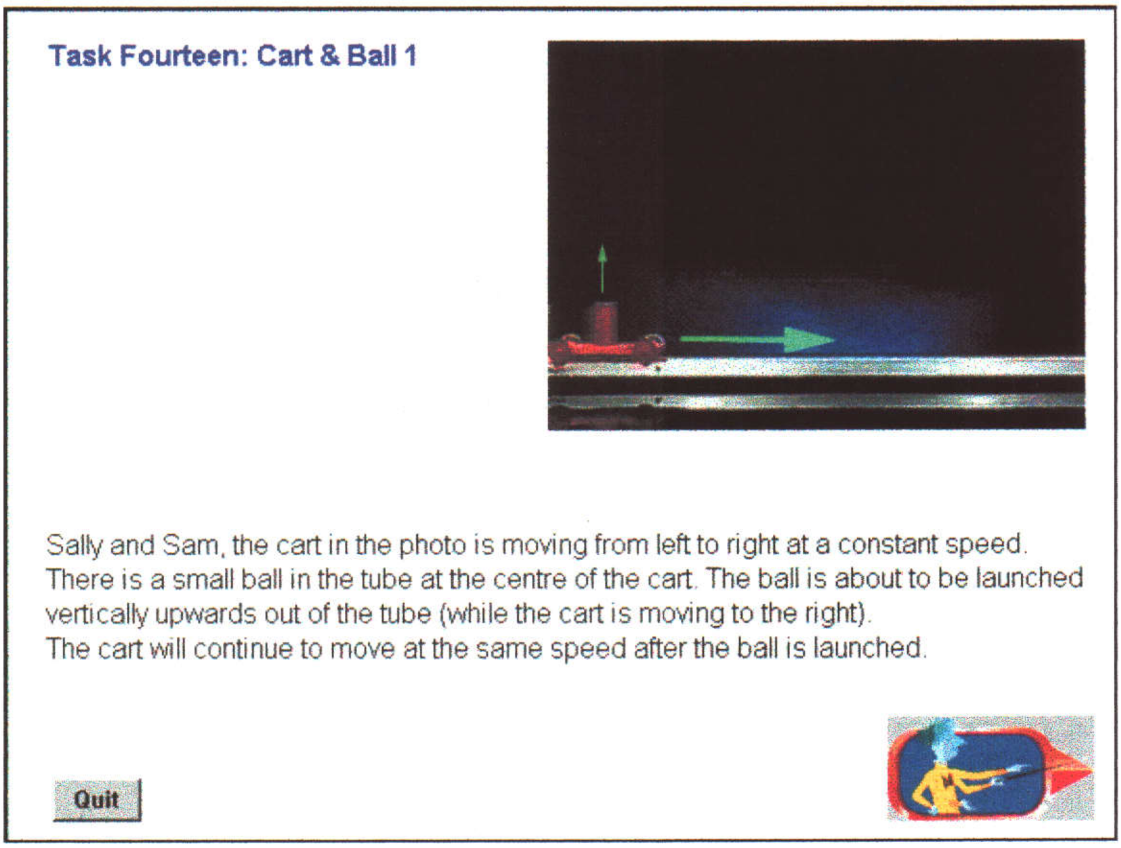
Prediction

Click on the button below which best corresponds to your prediction.

○ The ball on the left will land first

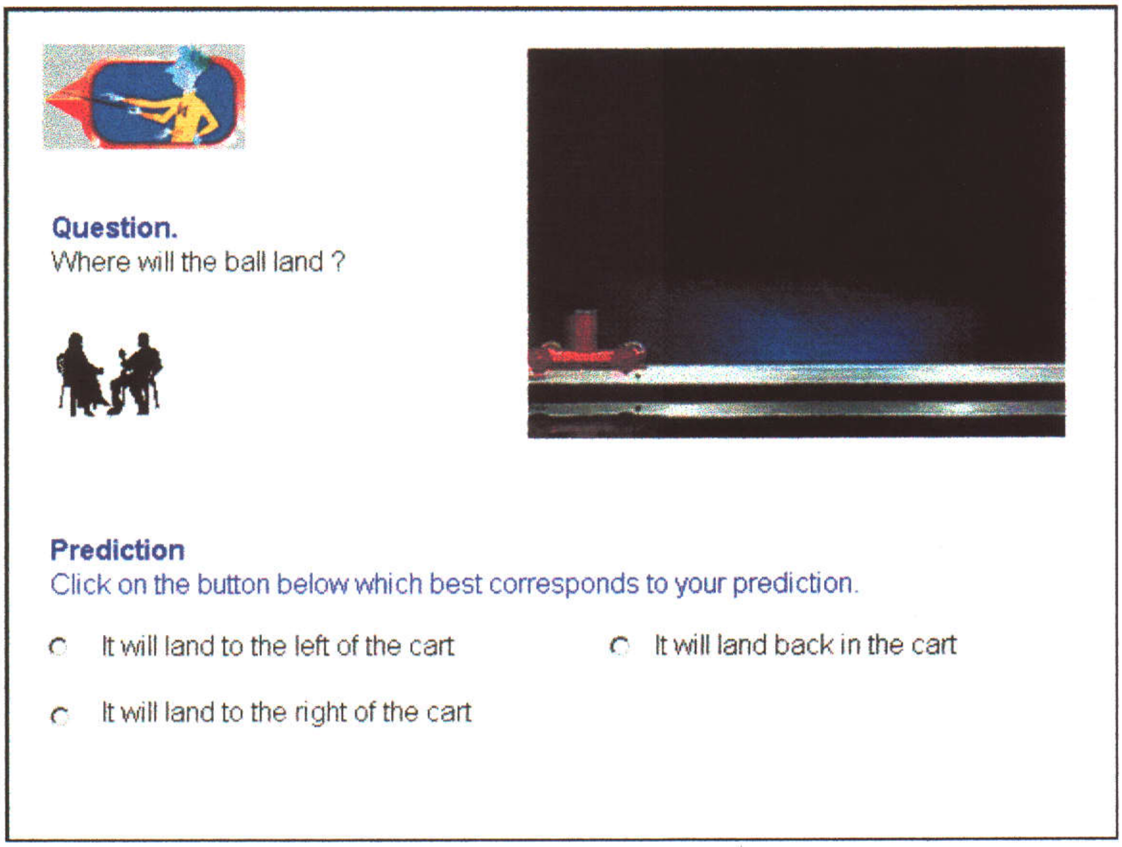
○ The ball on the right will land first

○ Both balls will land at the same time



Task Fourteen: Cart & Ball 1

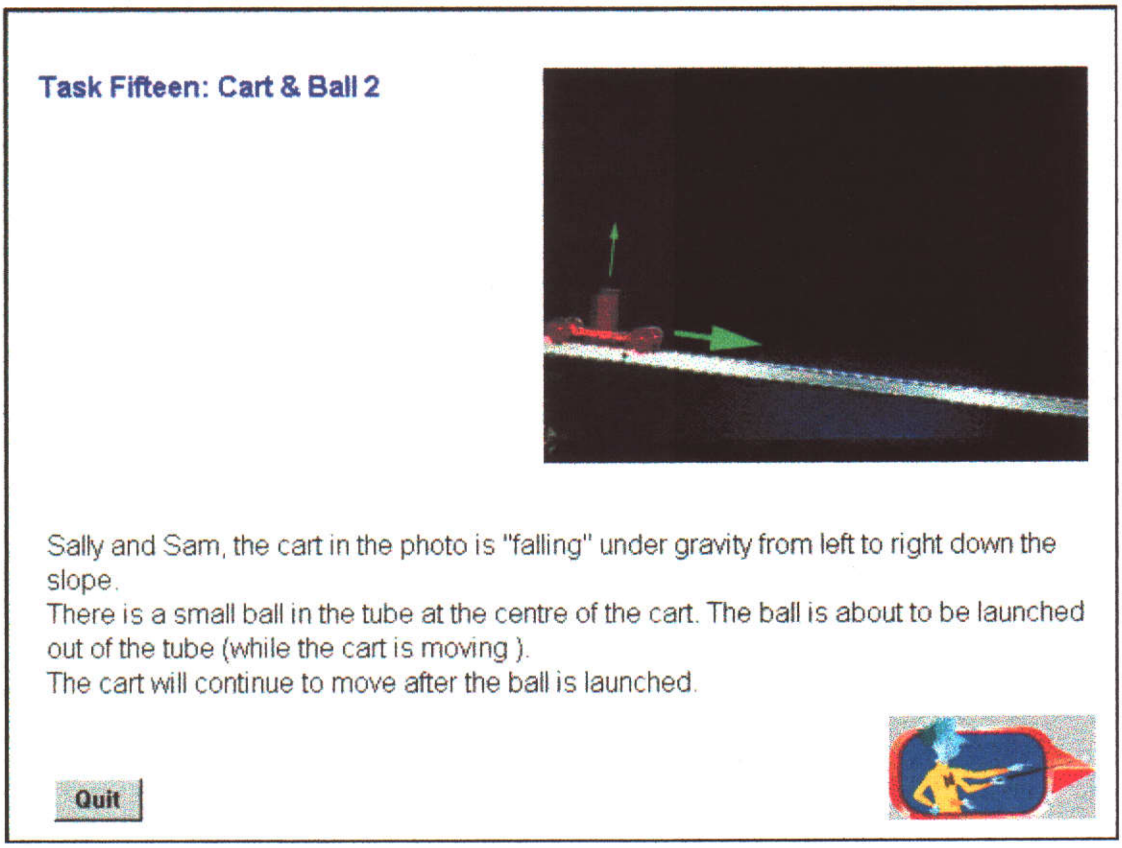
Sally and Sam, the cart in the photo is moving from left to right at a constant speed. There is a small ball in the tube at the centre of the cart. The ball is about to be launched vertically upwards out of the tube (while the cart is moving to the right).
The cart will continue to move at the same speed after the ball is launched.



Question.
Where will the ball land ?

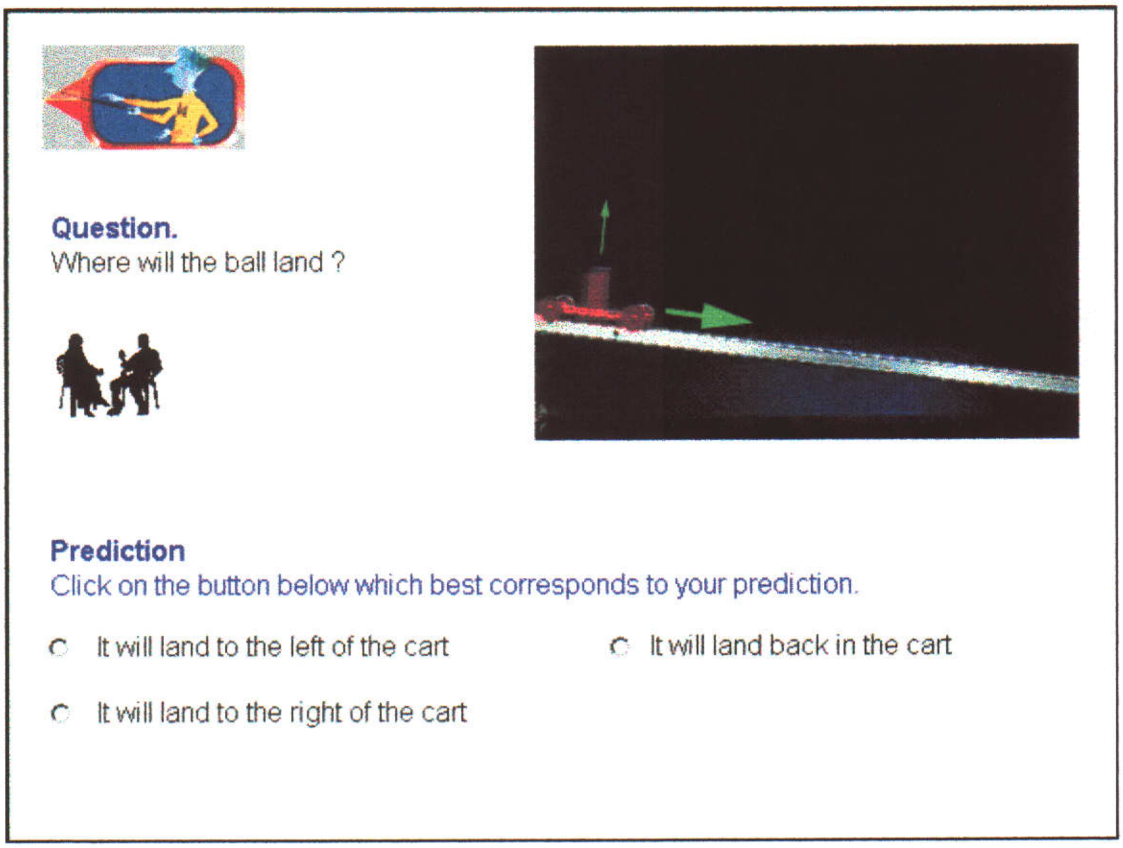
Prediction
Click on the button below which best corresponds to your prediction.

○ It will land to the left of the cart
○ It will land back in the cart
○ It will land to the right of the cart



Task Fifteen: Cart & Ball 2

Sally and Sam, the cart in the photo is "falling" under gravity from left to right down the slope.
There is a small ball in the tube at the centre of the cart. The ball is about to be launched out of the tube (while the cart is moving).
The cart will continue to move after the ball is launched.



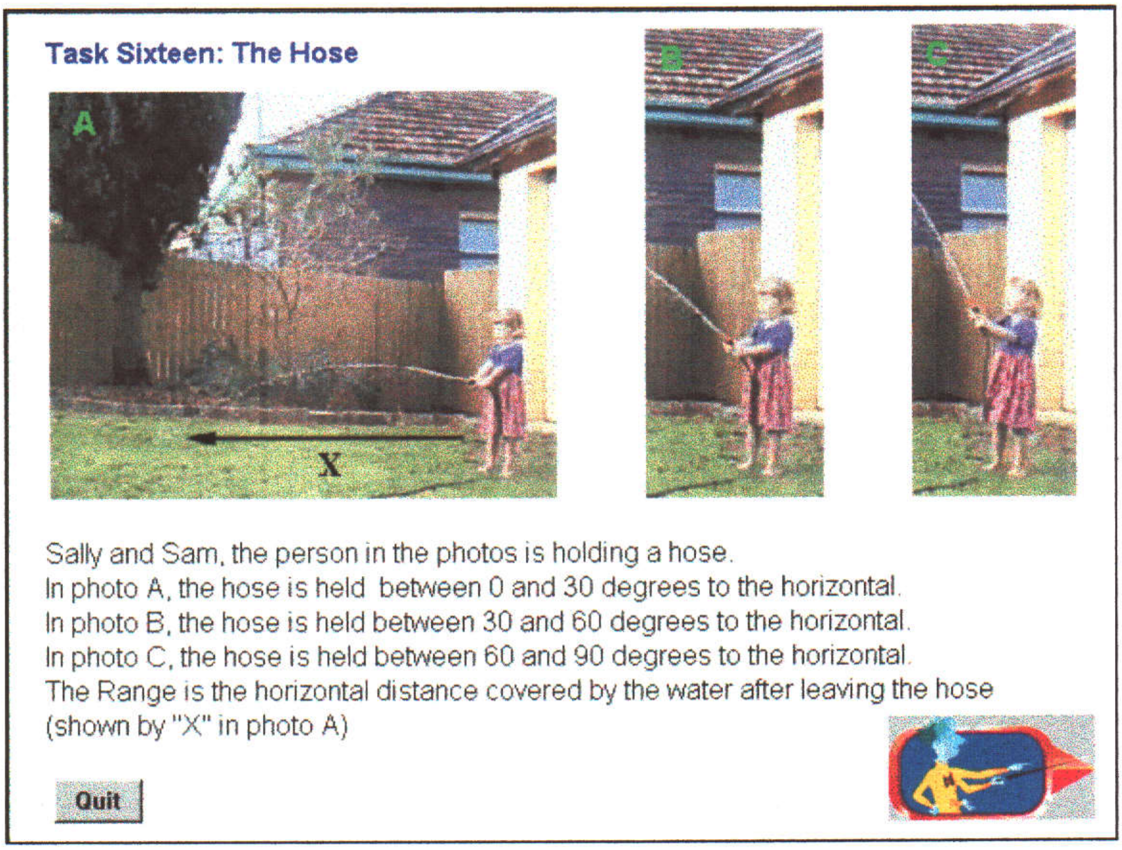
Question.
Where will the ball land ?

Prediction
Click on the button below which best corresponds to your prediction.

○ It will land to the left of the cart

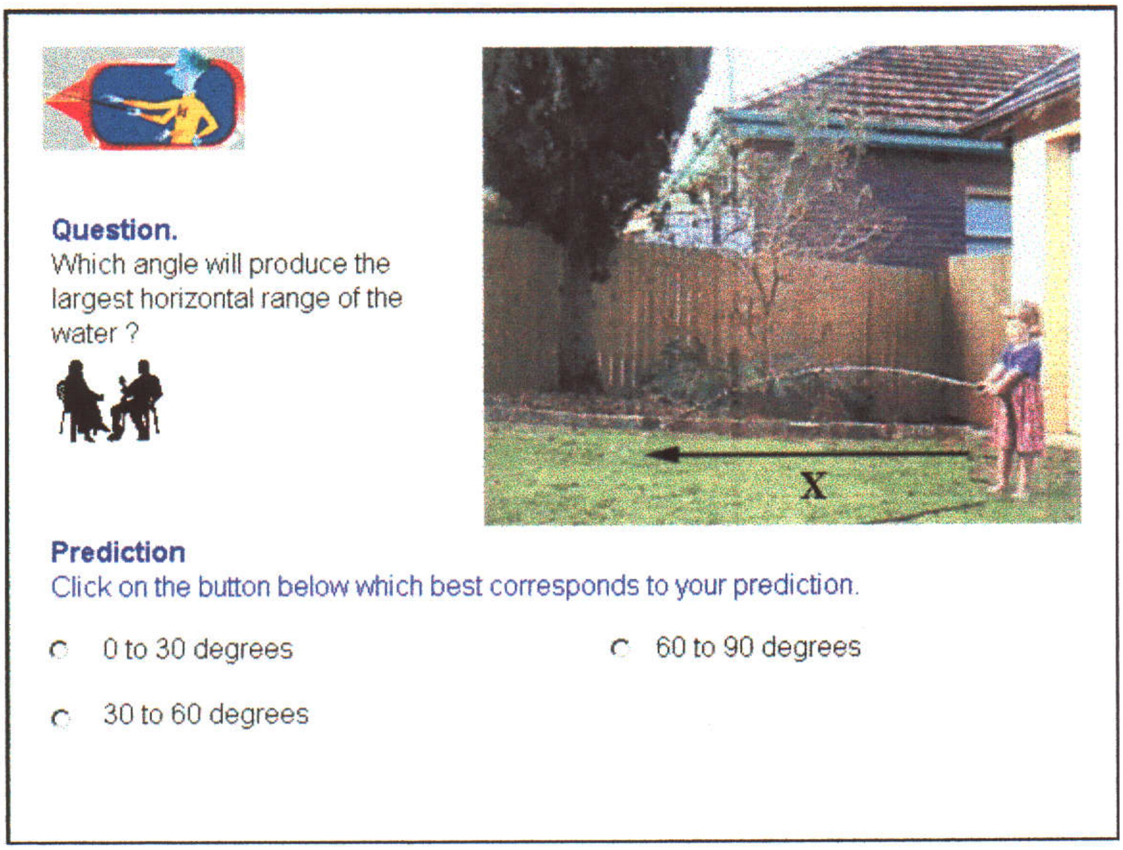
○ It will land back in the cart

○ It will land to the right of the cart



Task Sixteen: The Hose

Sally and Sam, the person in the photos is holding a hose.
In photo A, the hose is held between 0 and 30 degrees to the horizontal.
In photo B, the hose is held between 30 and 60 degrees to the horizontal.
In photo C, the hose is held between 60 and 90 degrees to the horizontal.
The Range is the horizontal distance covered by the water after leaving the hose (shown by "X" in photo A)



Question.
Which angle will produce the largest horizontal range of the water ?

Prediction
Click on the button below which best corresponds to your prediction.

○ 0 to 30 degrees
○ 60 to 90 degrees
○ 30 to 60 degrees

APPENDIX B
SAMPLE PRINTOUT OF STUDENT RESPONSES

These are the responses from Joan and Leigh (pseudonyms)
Date: Thursday, February 18, 1999
Start Time: 8:18 AM

TASK: 1. Falling Balls - girl dropping ball vertically down. (Vertical Motion)
QUESTION: Describe the motion of the ball as it falls.
PREDICTION: the ball will get faster
REASON: because it will gain momentum as it falls.
OBSERVATION: As it goes down, in each frame the length of the drop gets longer and therefore the ball is going faster.
EXPLANATION: Not really, however, it was made obvious when we viewed the clip frame by frame that the ball did gain momentum

TASK: 2. Rising Ball -girl throwing ball vertically upwards. (Vertical Motion)
QUESTION: Describe the motion of the ball as it rises.
PREDICTION: the ball will slow down
REASON: because gravity is working against the ball and as it reaches the peak of the throw, it will slow down, and fall back towards the earth
OBSERVATION: As it reaches the top it slows down and on its way back, it speeds up.
EXPLANATION: Not really, we did not, however account for the momentum it would gain on the way back down

TASK: 3. Ball Throw (Half Projectile Motion-Active Launch)
QUESTION: Predict the Pathway of the ball through the air.
PREDICTION: See Drawings for Task 3
REASON: Because gravity is working against the ball as it is thrown, and it was not thrown with a great deal of force, the ball will basically go down.
OBSERVATION: the ball goes up for a short moment before it goes down quite steeply.
EXPLANATION: yes. in our pre3diction we thought the ball would stay in the air and go horizontally for a longer period , however in the movie it was shown the balls path was more arc like.

TASK: 4.Slow Ball Roll off Table(Half Projectile Motion-Active Launch)
QUESTION: Predict the Pathway of the ball through the air.
PREDICTION: See Drawings for Task 4
REASON: Because it is not going very fast, the ball will not have the energy to be thrust into the air for a great deal of time, we therefore predict that the ball will basically fall straight to the ground.
OBSERVATION: The ball falls diagonally to the ground basically in a straight line.
EXPLANATION: yes. We thought the ball would fall vertically to the ground. however it more plight and it fell diagonally. It had more momentem then we suspected.

TASK: 5. Fast Ball Roll off table (Half Projectile Motion-Active Launch)
QUESTION: Predict the path the ball will follow in the air.
PREDICTION: See Drawing for Task 5.
REASON: because the ball is going at a faster speed , it will have the ability to be suspended in the air for a longer time period before gradually losing momentum and gravity will force it to the ground
OBSERVATION: The ball basically was thrust into the air with greater speed than the slow ball and was therefore carried a longer distance in the air before falling to the ground.
EXPLANATION: Yes, the ball went further than we predicted and did not fall as sharply

TASK: 6. Car (ie. Heavy Object) Jump off cliff (Half Projectile Motion-Active Launch)
QUESTION: Predict the path the car will follow in the air.
PREDICTION: See Drawing for Task 6
REASON: because the car is going fast, it will drive off the cliff, and keep moving horizontally for a time, then because of its weight it will fall sharply.
OBSERVATION: The car goes for a short distance in the air before falling vertically towards the ground
EXPLANATION: In our prediction the car was suspended in the air for a longer period of time and did not fall quite as sharply.

TASK: 7. Soccer Ball being kicked. (Full Flight Projectile Motion-Active Launch)
QUESTION: Predict the path the ball will follow in the air.
PREDICTION: See Drawing for Task 7
REASON: we predicted that the ball will move in an arc as it will be kicked upwards and across and once it reaches its peak it will fall in a similar path back to the ground.
OBSERVATION: The ball is kicked hard and rises to the top of it's flight, where it stays for a couple of seconds before falling on a similar path to the ground. It flew in an arc.
EXPLANATION: The shape of the path was nearly the same except the ball was higher than we expected and it stayed at it's peak for longer.

TASK: 8. Boy dropping ball from swing. (Three Quarter Projectile Motion-Passive Launch)
QUESTION: Predict the path the ball will follow in the air after the boy on the swing releases the ball.
PREDICTION: See Drawing for Task 8
REASON: our prediction is because he drops the ball while he is moving up the ball will suspend in the air for a second before dropping straight down.
OBSERVATION: The ball falls diagonally to the ground after it is released from the boy's hand. After the ball is released it goes up for a short period before falling, we suspect this is from inertia.
EXPLANATION: We thought the ball would fall straight to the ground, the ball did not do this, instead it rose a bit and then fell gradually (diagonally) to the ground

TASK: 9. Astronaut-Hammer & Feather dropped on moon (Vertical Motion)
QUESTION: Which object will hit the ground first?
PREDICTION: the hammer will hit the ground first**
REASON: Because the same amount of gravity is applied to both object the one with the heavier mass will reach the ground first.
OBSERVATION: The feather and the hammer fell to the ground at the same time.
EXPLANATION: we predicted they would fall seperately but they fell at the same time. This may be because the gravity is so minimal it is as though the objects are falling in a vacuum.

TASK: 10. Heavy Ball and Cup- (Half Projectile Motion-Passive Launch)
QUESTION: Does the ball land behind, in or in front of the cup?
PREDICTION: the ball will land in front of the cup
REASON: because she is walking while she releases the ball, the ball will have momentum to go forward.
OBSERVATION: The ball lands to the right side of the cup.
EXPLANATION: No, we predicted that the ball would fall in front of the cup because of momentum it had.

TASK: 11. Light Ball and Cup (Half Projectile Motion-Passive Launch)
QUESTION: Does the ball land behind, in or in front of the cup?
PREDICTION: the ball will land in the cup**
REASON: Because it is not heavy enough to have a strong enough momentum to carry it over the cup.

OBSERVATION: The ball falls in front of the cup.
EXPLANATION: Yes we thought the ball would not be heavy enough to keep going but in fact it was probably because it was light that the ball kept going. It may also have outside influences e.g. wind

TASK: 12. Sailing Boat-ball drops from mast (Half Projectile Motion-Passive Launch)
QUESTION: Does the ball land below, left or right of the mast?
PREDICTION: the ball will land to the left of the mast**
REASON: We think that the ball will fall nearly vertically (maybe a bit of curve) to the ground, by then the boat would have moved and the ball will land further back.
OBSERVATION: The ball falls basically straight down and lands behind the mast.
EXPLANATION: Not really except there is minimal curve and the wind factor and the weight of the ball were not taken into account, these could have had an effect on the outcome.

TASK: 13. Falling Balls-1 ball drops vertically, 1 is launched horizontally. (Half Projectile Motion)
QUESTION: Which ball hits the ground first (Vertically falling ball or half flight projectile?
PREDICTION: the ball falling vertically will hit the ground first**
REASON: because the ball on the right is going straight down and the one on the left is being projected in to the air so it has more force and the curve to the ground
OBSERVATION: They dropped at the same time and reached the ground together.
EXPLANATION: We thought the ball on the right would have more force behind it than it did so it would be suspended in the air for longer. But it didn't and they reached the ground together.

TASK: 14. Cart and Ball1-ball is launched vertically from moving cart. (Full Projectile Motion-Active Launch)
QUESTION: Does the ball land behind, in or in front of the cart?
PREDICTION: the ball will land back in the cart.
REASON: Because the ball has the same momentum as the cart as they were travelling at the same speed. The ball will be projected and move across back into the cart.
OBSERVATION: The ball lands back in the cart.
EXPLANATION: no not really, the ball did land back in the cart as it had the same momentum as the cart.

TASK: 15. Cart and Ball2 (Three Quarter Flight Projectile Motion-Active Launch)
QUESTION: Does the ball land behind, in or in front of the cart?
PREDICTION: the ball will land to the left (behind) the cart**
REASON: teh cart will gain speed as it goes from left to right. The ball will have the momentum of the cart as it is projected but will not gain the same momentum as the cart so the ball will land behind.
OBSERVATION: the ball lands back in the cart.
EXPLANATION: The ball obviously was under the same gravitational presure so it fell back into the cart as it moved from left to right. We had predicted the momentum of the two objects would be different, but they weren't.

TASK: 16. The Hose (Full Projectile Motion)
QUESTION: Estimate the angle of projectile to obtain maximum Range?
PREDICTION: the water will reach a maximum horizontal range between 60 to 90 degrees**
REASON: Because the water will always fall to the ground it will reach it's largest horizontal range when the hose is at the sharpest angle and projecting water straight up.
OBSERVATION: The arc is largest between about 30-60 dgrees
EXPLANATION: We made a mistake in thinking it was vertical rather than horizontal, we were therefore wrong and 30-60 was the correct answer. During this period the arc is the longest.

APPENDIX C

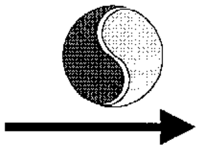
SAMPLE DRAWING SHEETS USED BY STUDENTS

The following pages show 2 sample (blank) drawing sheets used by students in the drawing section of the program. These particular sheets were used in tasks 3 (Ball Throw) and 6 (Car Launch).

Names : ______________________________

TASK 3: Ball Throw

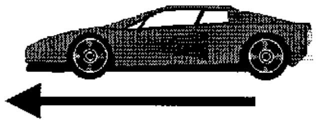
For Predicted Path: Use a Continuous Line (________); For Observed Path: use a Dotted Line (_ _ _ _ _)



GROUND

Names : ______________________________

TASK 6: Car Launch For Predicted Path: Use a Continuous Line (________); For Observed Path: use a Dotted Line (_ _ _ _ _)

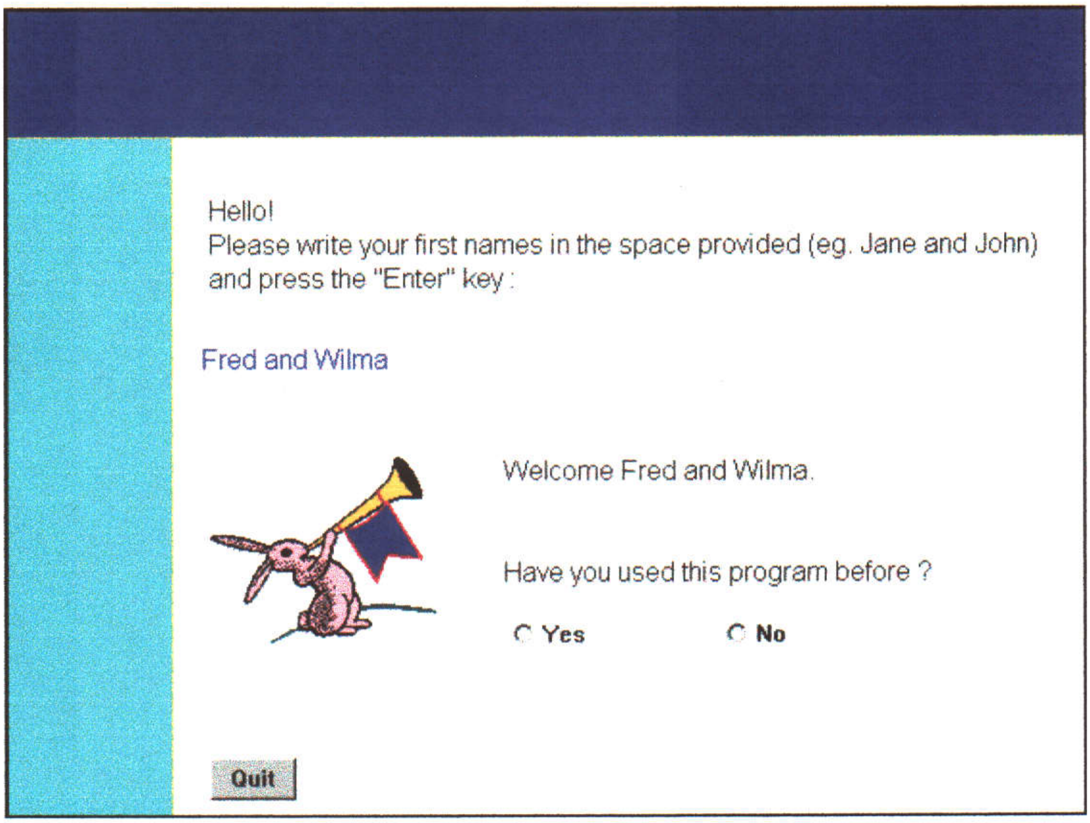


Ground

APPENDIX D

SCREEN SHOTS OF STUDENTS' INTRODUCTORY TUTORIAL

The following pages show screen shots of the students' introductory tutorial, completed before attempting the POE tasks. Refer to section 4.4.3 for discussion of this tutorial.



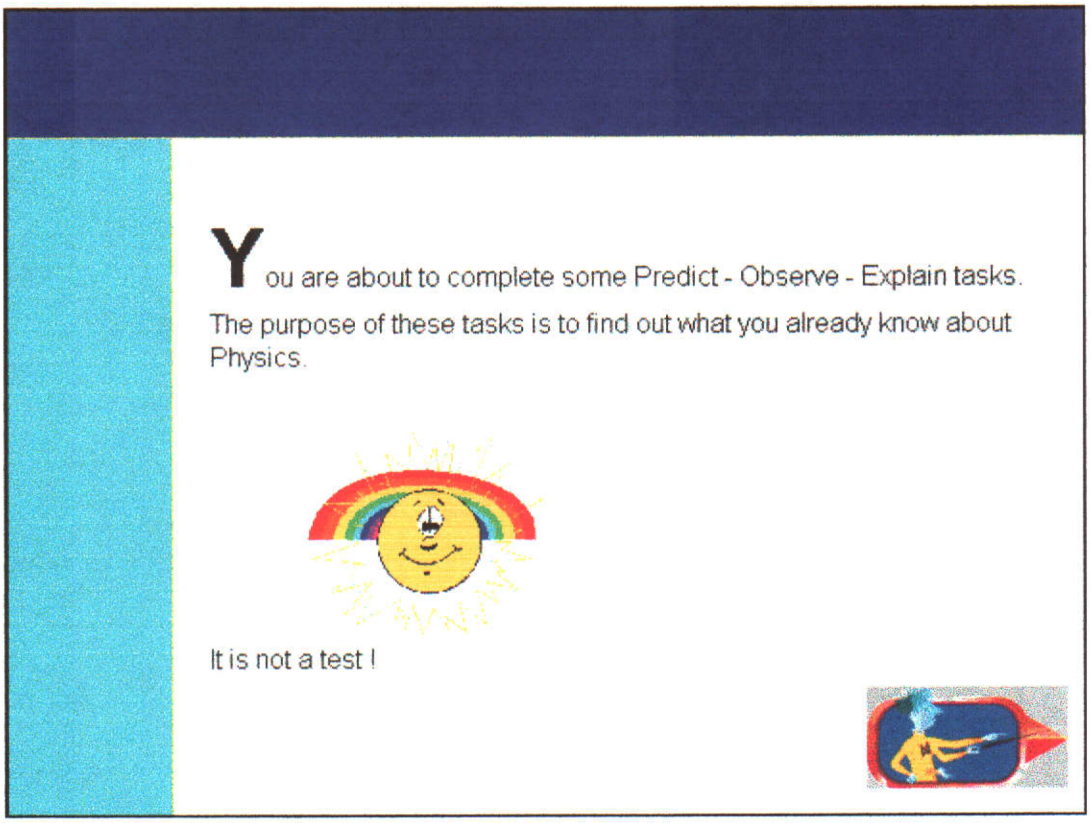
Hello!
Please write your first names in the space provided (eg. Jane and John) and press the "Enter" key :

Fred and Wilma

Welcome Fred and Wilma.

Have you used this program before ?

○ Yes ○ No



You are about to complete some Predict - Observe - Explain tasks.

The purpose of these tasks is to find out what you already know about Physics.

It is not a test !

Each task will involve :

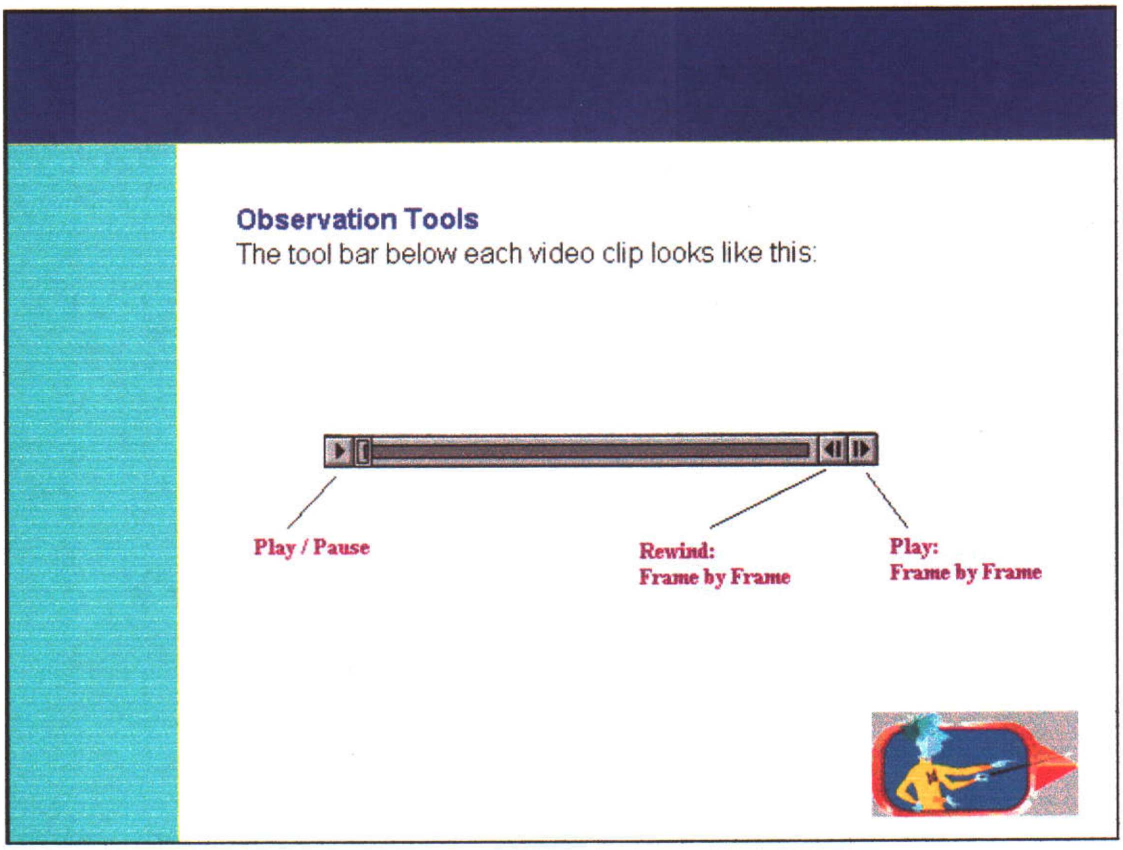
a) **Predicting** what will happen in a given situation (before you see it!)

b) **Observing** what happens using a video clip.

c) **Explaining** any differences between your Prediction and Observation.

It is important to **discuss** each situation with each other *before* writing your responses.

Please write all responses in full sentences.



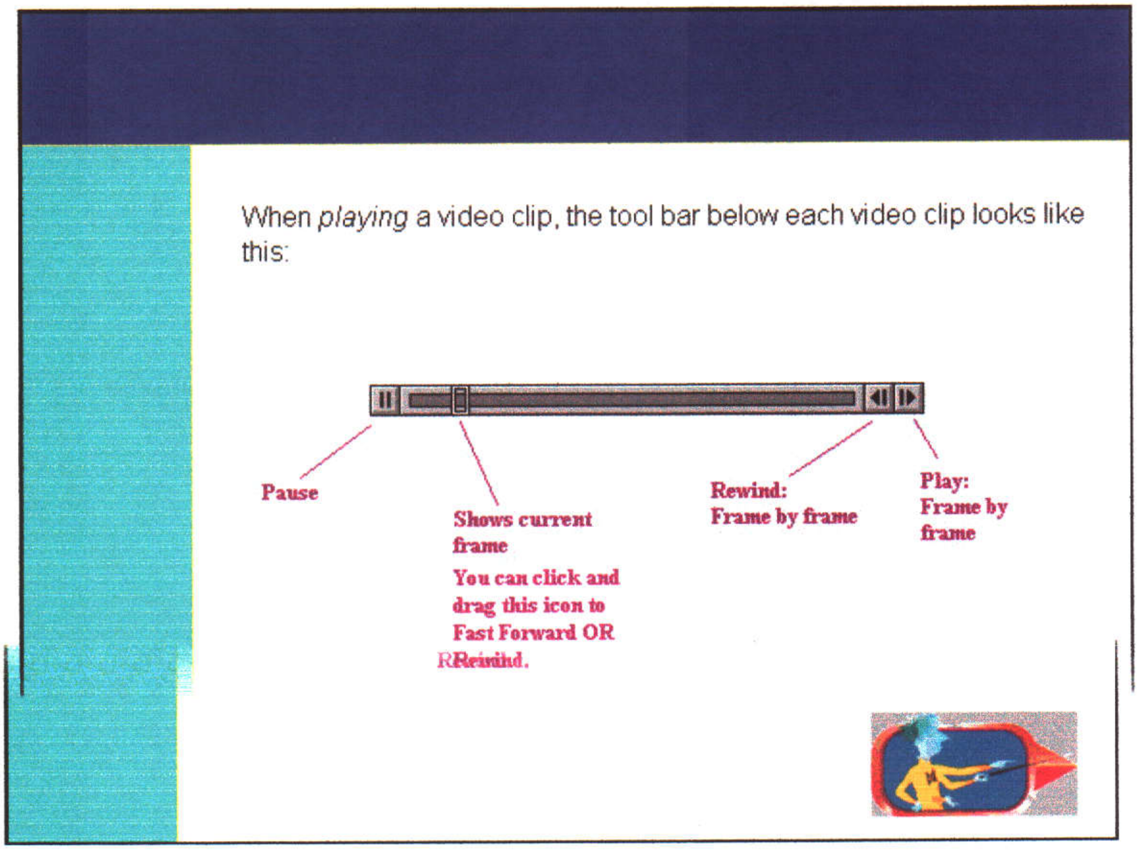
Observation Tools

The tool bar below each video clip looks like this:

Play / Pause

Rewind:
Frame by Frame

Play:
Frame by Frame



When *playing* a video clip, the tool bar below each video clip looks like this:

Pause

Shows current frame

You can click and drag this icon to Fast Forward OR RRewind.

Rewind:
Frame by frame

Play:
Frame by frame

"Frame by Frame":

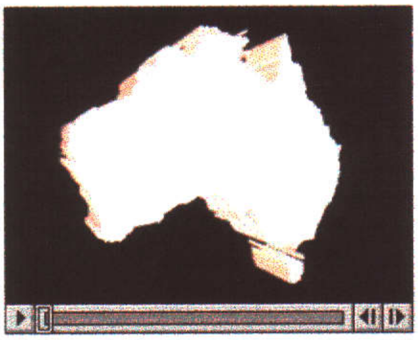
Be sure to look at each video clip carefully by using the "Frame by Frame" tools.

If you hold the mouse down on these buttons, you can REWIND or PLAY in "slow motion".

Important: The TIME between each Frame is EQUAL.

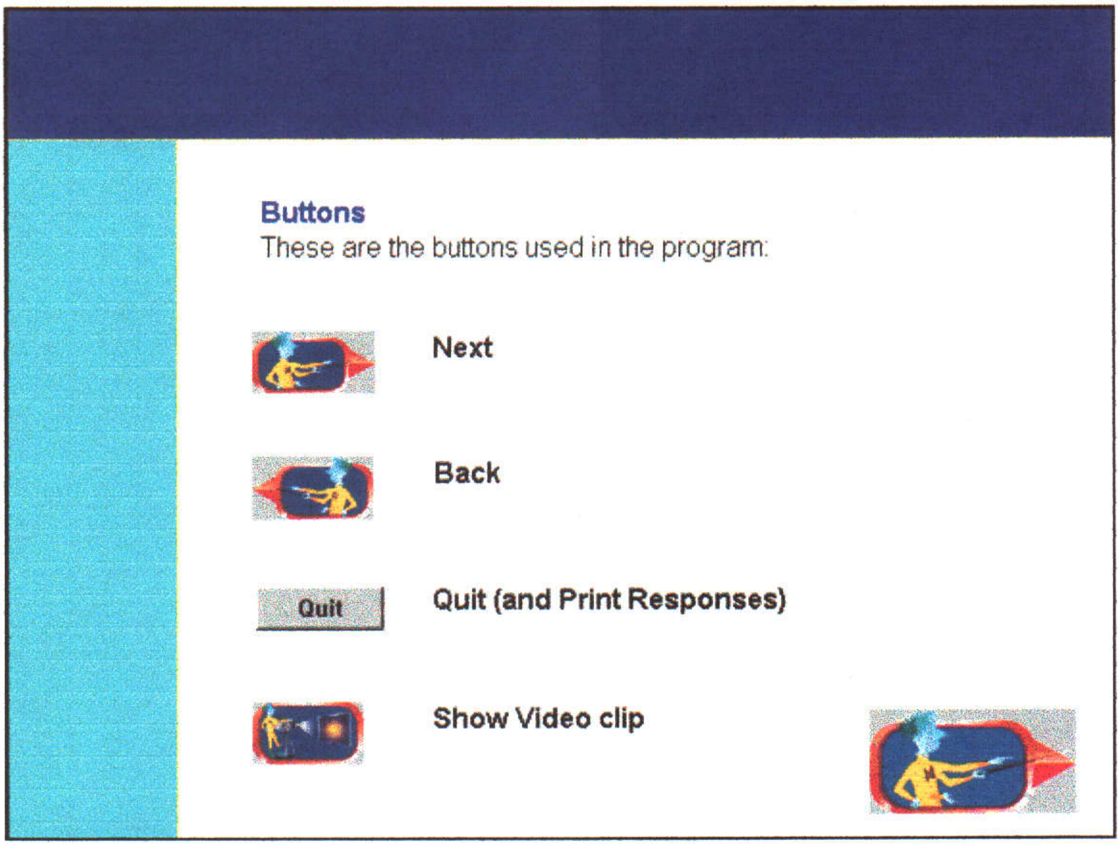
Sample Movie

Take a moment to practise using the movie tools.



Quick Quiz!

Ask your teacher to give you a quick quiz on the use of the movie tools. Good luck.



Buttons

These are the buttons used in the program:

Next

Back

Quit (and Print Responses)

Show Video clip

APPENDIX E
QUESTIONNAIRE INSTRUMENT USED BY STUDENTS

My Experience using the Predict-Observe-Explain (P.O.E) Computer Tasks

Name : ___________________________

Directions.

Thank you for taking the time to complete the Predict-Observe-Explain (P.O.E.) computer tasks. You now need to take a few moments to think about the time you spent with your partner completing the computer program.

The responses to each statement in this survey involve circling a number between 1 and 5. *Read each statement carefully* before deciding how well you agree with each statement:

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

Note: The words "*ideas*", "*views*" and "*opinions*" used in this survey refer to your own ideas *about motion* which you may have used, talked about, or just thought about while you and your partner used the computer program.

Your responses to this survey will remain confidential.

Thanks once again for your patience in completing these questions thoughtfully

1. The computer tasks encouraged us to talk to each other about our ideas.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

2. We sometimes argued about our responses.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

3. I changed some of my own ideas after talking with my partner.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

4. I often asked my partner questions.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

5. We had a good talk with our teacher on at least one occasion.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

6. My partner's views were of no interest to me.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

7. Some Predict-Observe-Explain (POE) computer tasks helped to confirm my own ideas about motion.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

8. My childhood experiences helped me to answer some questions.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

9. I could relate many of the video clips to my own past experiences.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

10. Some of the video clips had surprising outcomes.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

11. I found the video clips hard to control.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

12. Predict-Observe-Explain (POE) tasks are a waste of time.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

13. I am more confused about motion after using this computer program.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

14. My partner and I didn't talk much about our answers.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

15. I often challenged my partner's ideas.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

16. I felt that I needed more teacher guidance.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

17. I learned alot from listening to my partner's views.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

18. Some of the POE computer tasks caused me to change some of my own ideas about motion.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

19. My sporting background helped me to answer some questions.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

20. The video clips helped me to relate Physics to the real world beyond the classroom.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

21. The digital video clips were more relevant to me than pictures in text books.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

22. I found it easy to observe the outcome of each POE task from the video clips.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

23. I enjoyed doing the POE computer tasks.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

24. This program has motivated me to find out more about motion.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

25. My partner seemed to dominate our conversations.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

26. The teacher seemed to have plenty of time to answer our questions.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

27. My partner seemed to be interested in my ideas.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

28. Talking to my partner during the program helped me to clarify my own ideas about motion.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

29. I found the computer tasks quite irrelevant and meaningless.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

30. Many of the POE computer tasks were challenging to complete.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

31. I am quite curious to find out the correct answers to the POE tasks.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

32. It was really useful to play the video clip in “slow motion”.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

33. I was afraid of making a mistake in the computer tasks.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

34. I tried to change some of my partner’s ideas.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

35. This computer program helped me to realise how much I don’t know about motion.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

36. I had to rely on my partner for many answers.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

37. I found the video clips dull and boring.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

38. I often "replayed" the video to make sure of the correct outcome.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

39. This computer program was frustrating. I prefer doing teacher - led POE tasks.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

40. My partner became quite defensive about her own ideas on at least one occasion.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

41. I felt a little shy about giving my opinions on each computer task.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

42. I had to ask my partner to explain some motion concepts to me.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

43. The computer tasks raised many questions (about motion) which I would like answered.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

44. I felt that my partner wasn't listening to what I was saying.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

45. We guessed many answers.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

46. I find video clips more interesting than real life classroom demonstrations.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

47. I didn't enjoy using the video clips.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

48. I wanted to share my ideas with my partner but had difficulty explaining them

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

49. I often explained my own ideas to my partner.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

50. I felt that I didn't really participate in the POE tasks.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

51. My partner often referred to her own past experiences (eg. in sport, childhood games etc.) in our discussions.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

52. My views were completely different to my partner's views.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

53. I prefer the teacher to show us "live" demonstrations" rather than watching video demonstrations.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

54. I believe that I would have enjoyed this program more working by myself.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

55. I found it difficult to observe the outcomes of the video clips. Real life demonstrations are much easier to observe.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

56. I felt that the person at the keyboard had control of our group's responses.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

57. I listened carefully to my partner's ideas.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

58. I prefer to discuss demonstrations in a big class group led by the teacher, rather than with a partner on a computer.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

59. My partner and I worked well as a team.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

60. My partner often supported my own views.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

Comments: (Optional)

Thanks once again for your participation!

APPENDIX F
QUESTIONNAIRE USED BY TEACHERS

Teacher's Reflections on the Predict-Observe-Explain (P.O.E) Computer Tasks

Please take a few moments to think about the time you spent with the students as they completed the computer program.

The responses to each statement in this survey involve circling a number between 1 and 5. Read each statement carefully before deciding how well you agree with each statement:

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

Note: The words "*ideas*", "*views*" and "*opinions*" used in this survey refer to the students' own ideas about motion which they may have used, talked about, or just thought about while they used the computer program with their partners.

1. The program encouraged students to talk about their own ideas.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

2. I noticed some group members had conflicting ideas.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

3. I talked with many students about their ideas.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

4. The program is an inefficient way of probing students' personal science ideas.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

5. The program caused me to examine some of my own conceptions about Motion.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

6. I noticed some students referring to their past experiences (eg. childhood games, sport etc.) when attempting to answer questions.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

7. The computer tasks allowed me more time to help students.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

8. Students seemed to ignore one another's views.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

9. The computer environment made the POE tasks unrealistic and artificial.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

10. I would prefer to use other techniques (eg. student interviews, group reports etc.) to find out students' ideas.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

11. I could have performed many of the demonstrations in the program "live" to the students.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

12. I noticed that students were often asking each other questions.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

13. I would have preferred that the students used the program individually.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

14. The students often used the video tools ("play", "rewind", "pause", "slow motion" etc.) to carefully observe each video clip.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

15. The computer environment was motivating for the students.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

16. I noticed many students explaining motion concepts to their partners.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

17. Students found the video clips hard to control.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

18. Some students seemed to have trouble explaining their thoughts in words.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

19. The timing, pace and sequencing of the POE strategy was well controlled by the computer program.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

20. I prefer to discuss demonstrations in a big class group rather than working with small groups at a computer.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

21. Many of the POE computer tasks were challenging for the students to complete.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

22. I felt that many students didn't really participate in the POE tasks.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

23. I felt that I had more opportunities to talk with students compared to when we do practical experiments.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

24. Some students seemed to be very defensive of their own ideas.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

25. Some students were too shy to give their opinions on each computer task.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

26. Some students were curious to find out the correct answers to the POE tasks.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

27. The computer environment was distracting for the students.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

28. I plan to use the video clips again in future lessons.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

29. I felt that I had more opportunities to talk with students compared to when we do teacher-led demonstrations.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

30. I noticed some students changing their ideas as a result of their discussions with their partner (or with myself)

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

31. Some students were afraid of making a mistake in the computer tasks.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

32. The students were surprised by many of the demonstrations shown in the video clips.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

33. The digital video clips were more relevant to the students than pictures in text books.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

34. The computer environment was a cumbersome way of showing Physics demonstrations.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

35. The program helped students to relate Physics to the real world beyond the classroom.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

36. I noticed a few students changing their own ideas.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

37. The program effectively elicited students' own personal views.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

38. I felt alienated from the students' conversations.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

39. There seemed to be a dominating person in some groups.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

40. This program has motivated some students to find out more about motion.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

41. The outcome of each POE task was easy to observe from the video clips.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

42. I would prefer to show the students "live" demonstrations" rather than showing video demonstrations.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

43. There were many POE Tasks with surprising outcomes for the students.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

44. The video clips were dull and boring for the students.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

45. The computer controlled the presentation of the POE tasks as effectively as a teacher.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

46. The computer tasks were quite irrelevant and meaningless for the students.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

47. I discovered some common misconceptions through my conversations with different groups.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

48. There was too much “off task” talk.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

49. Students asked me many probing, meaningful questions.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

50. Students found the computer program frustrating. They would prefer to do teacher - led POE tasks.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

51. Most students seemed to express their ideas freely to their partners.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

52. Some students seemed to be more confused about motion after using this computer program.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

53. The program helped students to clarify their own ideas.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

54. My students find real life demonstrations more interesting than video clips.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

55. The video clips helped students to relate Physics to the real world beyond the classroom.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

56. The computer printout of the students' responses is a useful record of their ideas.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

57. I felt "powerless" having a computer present the demonstrations.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

58. Some students were guessing their answers.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

59. The program helped students become more aware of their own ideas about motion.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

60. My conversations with different groups were very superficial.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

61. Some group members were arguing about their responses.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

62. Students seemed to be much quieter than usual.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

63. Instructions given by the computer program were clear and concise.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

64. The students enjoyed doing the POE tasks on the computer.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

65. Students found it difficult to observe the outcomes of the video clips. Real life demonstrations are much easier to observe.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

66. The students enjoyed manipulating the video clips.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

67. The digital video clips provided interesting contexts for the students to consider motion concepts.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

68. Students could relate many of the video clips to their own past experiences.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

69. The computer tasks have caused students to become uninterested in their future studies of motion.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

70. I would prefer to lead the students through "live" POE demonstrations myself.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

71. Some students seemed to be quite aware of their partner's views.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

PTO.

72. My conversations with different groups gave me a good understanding of students' views.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

73. I found that I often had nothing to do during the lesson.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

74. There was a high level of meaningful conversation between the students as they used the program.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

Thanks once again for your participation!

APPENDIX G
COPY OF LETTER SENT TO PRINCIPALS

Matthew Kearney
...
..., NSW. ...
Ph./Fx ... (H)
Ph. ... (W)
email: ...

...
Principal
...
...
..., NSW. ...

Dear ...

My name is Matthew Kearney and I am a doctoral student from the Science and Mathematics Education Centre at Curtin University in Perth. (I actually live in Sydney). After teaching Physics and Junior Science at schools in the ACT and NSW, I currently work at Sydney University teaching science to overseas students.

My supervisor at Curtin is Dr. David Treagust. He is currently president - elect of the National Association for Research in Science Teaching. (He can be contacted at Curtin University by phone at (08) ...). I am currently conducting a Physics education research project that uses a computer program to encourage students to discuss their Physics ideas and also makes these ideas available for the teacher. The program is designed to be used at the beginning of a unit of study and should help students become aware of their own science views and also those of their peers. Teachers who use this program with their class should benefit from gaining an insight into what their students already know about a certain topic, and perhaps some alternative conceptions they may possess. The title of my thesis topic is: "An investigation of the classroom use of prediction-observation-explanation computer tasks designed to encourage student-teacher discourse and elicit student ideas."

I seek your permission for a Physics class at … to be involved in this study. This would involve a Year 11 Physics class using the program (in groups of two) during their study of "Mechanics" this year. During these lessons, the students' interactions with each other and the program would be recorded on video and audiotape. The study would also involve student and teacher interviews with me and the completion of some questionnaires. I would also need to observe the class before and after they use the program.

The computer program is very much relevant to the HSC Mechanics course. I believe that the computer program is enjoyable and motivating for the students and should help to promote the students' understanding of Mechanics concepts in their course.

All data collected by myself during this study will remain confidential. Names or other forms of identification of students will not be used in any documents associated with the research. (Eg. respondents will not be asked to write their names on any questionnaires). Pseudonyms will be used within the thesis. The name of the school used will also remain confidential.

All data collected will be securely stored on computer disk and retained by me at the Science and Mathematics Education Centre (SMEC) at Curtin University in a secure location for a period of five years. I will be the only person with access to this data.
Participating students may withdraw their participation at any stage of the study.

Please do not hesitate to contact me if you have any other concerns or queries.

Yours sincerely,

Matthew Kearney
(BSc. Dip.Ed. MEd.)

APPENDIX H
COPY OF LETTER SENT TO TEACHERS

Matthew Kearney
...
..., NSW. ...
Ph./Fx ... (H)
Ph. ... (W)
email: ...

Dear ...,

Thank you in advance for your interest in my research and for generously allowing me to use your class in the research.

If at any stage the research is intruding too much on your time (or your students' time), please let me know. Also, if at any time you feel like you'd prefer to "pull out" of the project, I will fully understand your decision.

I hope the project will benefit you and your students (I'm sure it will!)

Thanks again,

Matthew

APPENDIX I
COPY OF LETTER SENT TO PARENTS

Matthew Kearney
Science and Maths Education Centre
Curtin University
Perth, WA. 6845
Ph. …
Fx. …
Em. …

Dear Parent / Guardian,

My name is Matthew Kearney and I am a doctoral student from the Science and Mathematics Education Centre at Curtin University in Perth. My supervisor is Dr. David Treagust. I am currently attempting a Physics education research project that uses a computer program to encourage students to discuss their Physics ideas and also makes these ideas available for the teacher. The program is designed to be used at the beginning of a unit of study and should help students become aware of their own science views and also those of their peers. Teachers who use this program with their class should benefit from gaining an insight into what their students already know about a certain topic, and perhaps some alternative conceptions they may possess. The title of my thesis topic is: “An investigation of the classroom use of prediction-observation-explanation computer tasks designed to encourage student-teacher discourse and elicit student ideas.”

I seek your permission for your child to be involved in this study. This would involve your child’s Physics class using the program (in groups of two) at the beginning of their study of “Mechanics”. During these lessons, the students’ interactions with each other and the program would be recorded on video and audiotape. The study would also involve the completion of 3 questionnaires and possibly one interview with me.

All data collected by myself during this study will remain confidential. Names or other forms of identification of students will not be used in any documents associated with the research. (Eg. respondents will not be asked to write their names on any questionnaires). Pseudonyms will be used within the thesis. The name of the school used will also remain confidential.

All data collected will be securely stored on computer disk and retained by me at the Science and Mathematics Education Centre (SMEC) at Curtin University in a secure location for a period of five years. I will be the only person with access to this data.

Participating students may withdraw their participation at any stage of the study.

I believe that the program is enjoyable and motivating for the students. I believe that it will help promote the students' understanding of Mechanics concepts in their course and will also serve as a tool for their teacher to plan future experiences. You are most welcome to come and view the program yourself.

Please do not hesitate to contact the principal or me if you have any further questions.

Yours sincerely,

Matthew Kearney
(BSc. Dip.Ed. MEd.)

- -

PLEASE COMPLETE THIS FORM, TEAR OFF AND RETURN TO YOUR CHILD'S PHYSICS TEACHER.

I give permission for my child ____
to be a participant in the research study conducted by Matthew Kearney from the Science & Mathematics Education Centre, Curtin University, Perth.

Signed: ____________________________ Date: ________________________

APPENDIX J

SURVEY USED BY STUDENTS: CONSTRUCTIVIST LEARNING ENVIRONMENT SURVEY (CLES)—ACTUAL AND PREFERRED FORMS

The following pages show both the preferred and actual student forms of the Constructivist Learning Environment Survey (Taylor, Fraser, & Fisher, 1997). Refer to section 5.9.1 for discussion of this instrument.

APPENDIX K
QUESTIONNAIRE USED BY STUDENTS

My Attitude to Computers

Name: ______________________

Please take a few moments to think about your feelings towards using computers.
The responses to each statement in this survey involve circling a number between 1 and 5.
Read each statement carefully before deciding how well you agree with each statement.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

Your responses to this survey will remain confidential.

Thanks once again for your patience in completing this survey thoughtfully.

1. I am experienced using computers.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

2. I find that computers can help me learn.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

3. I am afraid of computers

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

4. I prefer to work with another person on the computer.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

5. I would prefer to use a pen and paper than type on a keyboard.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

6. I feel confident using computers.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

7. Using computers to help me learn is a waste of time.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

8. I like using computers.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

9. The main use for computers at school is to learn computer skills (typing, saving files, opening documents, using the "mouse" etc.).

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

10. My computer skills (typing, saving files, opening documents, using the "mouse" etc.).are very good.

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree