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Mental models of teaching, learning, and assessment: A longitudinal study.

Thesis submitted by

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ABSTRACT

This doctoral thesis is a significant research project that contributes to complete gaps in the literature on mental models of middle years school students and their teachers. The research aimed to determine how a study of a teacher's and students' mental models can inform the educational community about effective pedagogy. The research questions included the identification of the participants' mental models before, during, and immediately after applied problem-solving in a robotics program. A more in-depth investigation exposed the teacher's and four of her students' mental models of teaching, learning, and assessment. Once these mental models had been established, the matches, mismatches, and/or changes over time of such mental models and the effect, if any, on teaching, learning, and assessment were examined. The investigation was designed to understand how the mental models of multiple participants were managed over an extended period of time.

This empirical qualitative study was centred within information processing theory and linked with the introspection mediating process tracing paradigm. The study involved close contact with the participants over an extended period of time. The methodology focussed on learner centredness and how the participants integrated new experiences with existing conceptual, declarative, and procedural knowledge in the areas of teaching, learning, and assessment. This was not a simple "input-output" focus, but rather an investigation that ascertained the mental models of the teacher and learners as they carried out pedagogical tasks. It made no fundamental assumptions about links between input, for example, the lesson, and action but utilised mental model theory to understand the participants' mental models.

The study used a technology-based learning context, robotics, although the findings could be applied across curriculum areas. It was situated in a suburban Australian school and involved one Year Six teacher and a group of 24 volunteer students from her shared class of 54 students. Four of these 24 students were selected anonymously from face-down piles of names and participated in the in-depth aspects of the study. Rigorous adherence to ethical procedures was maintained throughout the study.

Data collection tools used to identify the participants' mental models included Likert Scale Questionnaires, Semi-Structured Interviews (individual and shared), Stimulated Recall Interviews, Participants' Journals, a Teach-Back episode, a Focus

Group Interview, and the Researcher’s Journal. The study’s pre-experience investigations commenced in March 2005 and the post-experience phase occurred six months later in September, 2005.

The study found that specific teaching strategies are required to identify and redress ineffective mental models that inhibit the students’ active participation in problem-based learning activities. Significant remediation was apparent for two of the participant students: one who failed to manage her mental models of problem-solving; one whose mental models of working with others inhibited her capacity to engage effectively in a social constructivist environment. Implications from these findings include a recommendation that teachers avoid making assumptions about students’ ability to engage effectively either with discovery-based learning activities or with their peers without the relevant scaffolded instruction.

The study also determined that mental models are, in the main, stable over time. This finding is significant and has implications for remediation if the established mental model is inaccurate or incorrect and, therefore, limits application or communication of effective problem-solving efforts. The implication is for teachers to ensure that students are engaged in challenging learning experiences that enable the development, application, and communication of accurate and effective conceptual, declarative, and procedural knowledge. The reflective application of such knowledge enables students to create processes for and products of learning: robust, rich, and useful mental models.

This unique longitudinal study of mental models offers significant data to the educational community’s constant quest for relevant information about productive pedagogical practice in the middle years of schooling.

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CHAPTER ONE: *Introduction*

Introduction

Mental models of teaching, learning, and assessment: A longitudinal study is a study of the mental models of a teacher and her students who undertook a journey of learning in robotics. A thorough search of literature on mental models of teaching, learning, and assessment did not locate information on pedagogical issues about how students and their teachers, in the middle years of schooling, negotiate a discovery-based learning experience, such as robotics, in a social constructivist environment. This doctoral thesis is a significant research project that contributes to complete these gaps in the literature on mental models of middle years school students and their teachers. This introductory chapter describes the thesis in terms of the research aims, its voice and literary aspect, methodology, scope, and limitations of the study, and the contents of each chapter.

The Research Aim and Research Questions

The research aimed to determine and examine how a teacher's and students' mental models can inform teaching, learning, and assessment. Four research questions, designed to support this aim, were: (1) what are the mental models of primary school students and their teacher before, during, and immediately after technology-based learning experiences? (2) What are a teacher's and four of her students' espoused, in-action, and reflective mental models of teaching, learning, and assessment? (3) In what ways have these mental models matched, mismatched and/or changed, and the effect, if any, on teaching, learning, and assessment? and, (4) In what ways have the mental models managed the participants or been managed by the participants longitudinally? The answers to these questions would enlighten the research community on the quality of engagement in pedagogical practices. Multiple participants and their multiple pathways were identified, mapped, and compared.

Methodology, Scope, and Limitations

Methodology

The methodology used for the study is positioned within the information processing paradigm. It focussed on learner centredness and how the participants, with whom close contact was maintained over an extended period of time, integrated new experiences with existing conceptual, declarative, and procedural knowledge in the areas of teaching, learning, and assessment. This was not a simple “input-output” focus, but rather an investigation that ascertained the mental models of the teacher and learners as they carried out pedagogical tasks. It made no fundamental assumptions about links between input, for example the lesson, and action but utilised mental model theory to understand the participants’ mental models. A variety of data collection methods were used including interviews, questionnaires, journals, and teach-back (Chapter 3). Rigorous adherence to ethical procedures was maintained throughout.

Scope

The study used a technology-based learning context, robotics, although the findings could be applied across curriculum areas. It was situated in a suburban Australian school and involved one Year Six teacher and a group of 24 volunteer students from her shared class of 54 students. Four of these 24 students were selected anonymously from face-down piles of names and participated in the in-depth aspects of the study.

The study was longitudinal and commenced with the first collection of data in March 2005 and the last collection in October 2006. A timeline of data collection including associated detail of type, participants, and time taken is provided in Chapter 3. Some instruments were conducted continually, such as the participants’ journal while others, such as Teach-back, were single events. The diversity of the type and time provided data suitable for the investigation of the richness of mental models.

Limitations

The limitations of the study include its lack of a gender variable. Gender consideration, particularly in design and technology education, could contribute significantly to the research community. Another limitation was the size of the study’s population. While the longitudinal aspect of the study has contributed to our knowledge of mental models over time, the size of the population could be increased to enhance its findings.

Thesis Format

Voice and Literary Aspect

The thesis is written in third person although the use of first person is common. This decision was made to remove any ambiguity from a reader's determination as to whom the discussion concerns. Clarity of the writing is enhanced due to this editorial style.

A literary theme has been woven through the thesis. When this research commenced, the author was teaching at the school used in study. The motion picture trilogy, *The Lord of the Rings* (Jackson, 2001, 2002, 2003), had been watched with great enjoyment by most of the students so, *The Hobbit*, another shorter story written by J. R. R. Tolkien in 1937, was chosen as the class book for the students. The story predates the adventures in *The Lord of the Rings* and describes the journey of enlightenment and self-discovery for its central character, Bilbo Baggins. This passage of enlightenment became synonymous with the author's research and the participants' learning journey.

While the use of a literary theme in a dissertation may not be the "norm", it is an integral element of this author's individual mental model of the study and analogous of the many twists, turns, and treasures she experienced along the way. Chapters begin with extracts from *The Hobbit* that were selected because they indicate a particular place along the research pathway. Selected adventures of Bilbo's journey are also used analogously to link similar experiences being shared by the participants. An example of this connection is word-play between Bilbo and Gollum as they traded riddles. Their use of analogy, metaphor, and memories are examples of Chapter Two's discussion of Senge's (1992) multifarious nature of mental models which are "inextricably woven" (p. 37) into our individual life tapestries.

Document Format and Pseudonyms

The writing of the thesis commenced with the support and guidance of the American Psychological Association (APA) *Style Manual*, Fifth Edition (2001), Eleventh Printing December 2007. This reference style includes the italicisation of a book title (APA, 2001, p. 223) and the use of spacing has been adjusted to enhance readability (APA, 2001, p. 326), and figures and tables have been incorporated at suitable points in each chapter (APA, 2001, p. 325). All participant names in the thesis are pseudonyms in order to meet requirements with respect to ethics when researching with individuals who could otherwise be recognised.

Chapter Outline

Chapter One: Introduction

This introduction to the thesis outlines its purpose, the context of the research, and an explanation of its structure. It includes a rationalisation of the use of the literary theme, which is an obvious deviation from the norm. It provides an outline of the study's methodology, scope, and limitations. Each chapter's content is explained.

Chapter Two: Literature Review

As one stands on the doorstep of a new adventure, an assessment of the required knowledge for the journey is conducted. A review of mental model literature is presented in this chapter. The nature and functions of mental models are explained as the author moves toward a rationalization for the diverse definitions that have contributed to existing knowledge. A section that covers the distribution of mental models is included because the participants would be learning in a social constructivist environment. Robotics, as a component of the Queensland Technology Syllabus is described. The rich discussion of assessment that will weave its way through several chapters (see Chapters 7, 8, and 9) is commenced here.

Chapter Three: Methodology

Before taking the first step on the journey, what conveyance is needed to advance? What instruments and methods will one use to move forward? This chapter elucidates the objectives, that were introduced in the Abstract, in more depth. It then provides a thorough explanation of the methodological tools used to collect the study's data. A timeline is provided to show when those tools were used throughout the 20 months of the study and a detailed table is provided of the elements within the methodological design. The research significance of two of these data collection tools are introduced in this chapter and are explored in more depth in Chapter 5 and Chapter 7.

Chapter Four: Pre-Experience Mental Models

Data collection begins with the first round of Likert Scale Questionnaires, Semi-Structured Interviews, and Journal entries. This chapter discusses the pre-experience or espoused mental models held by all of the participants about robotics, social constructive learning situations, problem-solving, and predictions of success. It includes tables of information showing how the participants responded to various probes while outlining the data collection methodology used to gain such insights.

Chapter Five: In-Action Mental Models

This is not a chase about the countryside, but a discussion of those moments, during a project that test, and ultimately enlighten, a researcher who must search for clear solutions when faced with insufficient material from data collection to conduct an analysis. Adaptations to Stimulated Recall interview protocols are explained and the implications for working with younger research participants are explored in some depth. The results of those protocol adaptations are clearly shown providing evidence of the efficacy of the changes. The participants' in-action mental models of working in a robotic environment are externalised and analysed helping to provide a clearer picture of how the participants perform pedagogically through the project.

Chapter Six: Post-Experience Mental Models

Post-experience, or reflective, mental models are externalised through the re-application of data collection methods used in Chapter Four. This chapter provides graphical evidence of the changes in, or constancy of, the participants' mental models six months after the commencement of the project. How the students apply problem-solving mental models to negotiate social situations and the activities within those contexts are becoming clearer. These mental models provide a solid bench-mark for further analysis in the next stage of the study.

Chapter Seven: Teach-Back and Focus Group

Two methods of investigating the student participants' mental models of teaching, learning, and assessment are revealed in this chapter that describes how the students are exposed to challenging pedagogical situations. The students teach and assess other students and then distribute their mental models verbally in a group interview. Data are analysed in light of previously revealed mental models in Chapters 4, 5, and 6. This data also provides a comparative base for the longitudinal aspects that follow.

Chapter Eight: Longitudinal Mental Models (March 2006)

This chapter is a return, in March 2006, to the teacher and four students who participated in the more in-depth parts of the study. The teacher has remained at the school and is teaching robotics to a new cohort of students. The four students have not continued to learn with robotics: two of the students remain at the school in different classes; two students have moved to other schools out of the district. All participate in interviews that reveal their longitudinal mental models of their experiences of teaching, learning, and assessment.

Chapter Nine: Longitudinal Mental Models (October 2006)

The last round of data collection, held in October 2006, is presented in this chapter. This penultimate chapter focuses on the data collection methods used to externalise longitudinal mental models. It is rich and robust and offers important aspects of a long-term investigation into mental models. The cast is reduced with the teacher and two students remaining. They have travelled far on their journey and their reflections offer significant insight into how mental models matter in pedagogical practice.

Chapter Ten: Conclusion

The concluding chapter in this thesis provides an exhaustive discussion on the contribution this study has made to both qualitative methodology and to the education community's knowledge of mental models. It explains in more detail the limitations of the research, already mentioned earlier in this chapter. This explanation is followed by a review of the pedagogical implications for teaching, learning, and assessment, such as the timeliness of intervention strategies and the need for teaching fundamental collaborative strategies for social constructive contexts. It closes with a recommendation for proactive strategies for improved outcomes in problem-solving.

And so the story starts …

We leave this introduction to commence the journey. Gandalf, the wizard in *The Hobbit*, sought Bilbo's help for an exciting and dangerous quest. Bilbo was unsuspecting of the trials ahead but could retrieve a novice mental model of adventures that prompted him to say, "We are plain quiet folk and have no use for adventures. Nasty disturbing uncomfortable things! Make you late for dinner! I can't think what anybody sees in them" (Tolkien, 1937, p. 6).

CHAPTER TWO: *Literature Review*

> You said sitting on the doorstep and thinking would be my job, not to mention getting inside, so I am sitting and thinking. But I am afraid he was not thinking much of the job, but of what lay beyond the blue distance, the quiet Western Land and the Hill and his hobbit-hole under it. (Tolkien, 1937, p. 193)

Introduction

Teachers observe students in classrooms and make judgements about what they are thinking throughout teaching and learning experiences. A creative teacher will plan learning experiences, such as robotic design and programming, simultaneously with appropriate assessment strategies and instruments designed to illuminate and measure cognitive change. Professional consideration of the thought processes of students, before, during, and after a learning experience, underpins what teachers do. These considerations are based on professional judgements that are strengthened over time through constant exposure to a multiplicity of differing individual students and their level of involvement, interaction, and success in the various and diverse learning experiences to which they are exposed.

It is reasonable to assume that these considerations are sometimes erroneous. It is also reasonable to assume that teachers cannot always know exactly what is going on in the heads of their students although years of practice, and the relationships developed in the classroom environment, may go some way to enlightening them of the possible thoughts of their students. The study of mental models enables us to appreciate the thoughts behind the actions and decision-making that occurs in classrooms when teachers and students interact with each other and with instructional media. The study of mental models enables us to understand the matches and mismatches (Bibby, 1992; Johnson-Laird, Oakhill & Bull, 1986; Larkin & Simon, 1987) that can occur amongst those thoughts, actions, and interactions with phenomena. The matches and mismatches of mental models can promote or hinder learning and the authentic assessment of that learning.

Did Gandalf, the wizard in *The Hobbit* (Tolkien, 1937), know what the book's hero, Bilbo Baggins, was really thinking? When faced with a problem for that he had no immediate answer, Bilbo's thoughts drifted to familiar places: places that in some way held clues to the apparently insurmountable problem that lay ahead. The tightly-sealed rock that contained the doorway, outside of which the hobbit was sitting, was literally a closed door in which there was no apparent key-hole. Bilbo was drawing on mental models from previous experiences and knowledge to assist him with the problem of opening the door. What were these mental models and how could they help him with the problem at hand? This chapter critically reviews mental models and examines the theory that underpins them. It discusses the ways that can assist the development of strategies within classrooms that foster and promote the individual learner's ability to effectively utilize mental models to problem-solve in unique situations.

Mental Models

The Journey to Find a Definition

Finding a definition of mental models is problematic due, in part, to the diverse research contexts in which they have been studied. Nevertheless, there are some commonalities. Mental models are seen to be purposeful in that they are cognitive structures that function as storage facilities (O'Malley & Draper, 1992; van der Veer & Peurta-Melguizo, 2002) and/or problem-solving centres (Johnson-Laird, 1983; Newton, 1996) that enable the individual to function in novel situations with real world phenomena, regardless of context. Bilbo Baggins was in a novel situation when he sat near the charmed stone that was blocking the entrance to the Lonely Mountain. What resources, concepts, or analogies could he draw on to move the stone, thereby enabling access to the treasure that lay beyond? What mental models would the teacher and students, in this study, create to find their way through the robotics program successfully? Mental model theory provides an explanation of how individuals use memory and link information with innovative, personalised strategies to find solutions to problems. Indeed, mental models are assumed to "form the basis of all human behaviour" (Barker, van Schaik, & Hudson, 1998, p. 104). Norman (1983) and, later, Jonassen (1995) believed that mental models are complex and inherently epistemic thereby providing a platform from which we express what we know.

The word "model" is used for two grammatical purposes: as a *noun* where it determines "a representation in three dimensions of an existing person or thing or of a proposed structure", or as a *verb* "to form a thing in imitation of . . . a phenomenon or system" (Moore, 1987, p. 900). The term, "mental model", is similarly bimodal: (i) as a *product* (Gentner & Stevens, 1983; Henderson & Tallman, 2006; Johnson-Laird, 1983; Newton, 1996) created by individuals who have used their cognitive functions in the broadest possible way to create a representation or structure of a phenomenon or solution to a problem, and (ii) as a *process* (Carroll & Olson, 1988; Halford, 1993; Henderson & Tallman, 2006; Norman, 1983) to form such a model or representation of a structure of a phenomenon or solution to a problem. Therefore, individuals create, or call upon existing, mental models when undertaking the process of mental modelling in order to devise more useful or refined mental models. Where a model, in its purest form, may be a reproduction of the reality of a phenomenon in an environment, a mental model has, in essence, a dynamic existence separate to such reality once it has been produced by the individual. When the mental model is stored in long-term memory, it may be related or connected to many other cognitive structures or senses but it exists within its own reality and no longer relies on the replication of its source phenomenon (Barker, 1999b). An individual creates, stores, and retrieves a mental model in accordance to its perceived relevance and usefulness for novel problem situations.

The following sections of this chapter weave a pathway through mental model theory and offer profundity to the definition provided in the overview in the preceding paragraph. This short journey will (a) discuss the attributes of mental models in their product/process orientation, (b) review the functions of mental models, and (c) demonstrate how novice and expert learners use them for their journey. First, the reader will be guided through comparisons of mental models with other cognitive structures.

How Mental Models Compare with Other Cognitive Structures

The idea of learning through engagement in problem-solving activities, such as robotics design and programming, or the disequilibrium that comes from comparing what is being considered as a solution to what is known as a possible response, bears some relationship to Jean Piaget’s (1970) work on cognition. He used the term, *schemes*, to label the cognitive structures a learner uses to assimilate new experiences when they face new situations. A learner will compare new experiences to their existing schemes already constructed from previous experiences and knowledge. If a new experience cannot be assimilated into an existing scheme, more radical accommodation has to occur to adjust to the disequilibrium created by the new situation. A new scheme would then be created: a process that leads to cognitive growth or learning (Piaget, 1970). Anderson (1977) conducted further research on Piaget’s ideas to develop schema theory where knowledge was organised in elaborate networks of related understandings that enabled an individual to operate in, and react to, the world around them. While schema and mental models share commonalities, schema cannot “account for novel situations, new actions or new arguments” (Schwamb, 1990, p. 30) as do mental models (Johnson-Laird, 1983).

Kyllonen and Shute (1989) created a taxonomy of knowledge types that can illuminate the relationship between schema and mental models. Propositions are at the base line of knowledge type and represent simple declarative knowledge (Kyllonen & Shute, 1989), including abstract symbols and definitions of single items (Johnson-Laird, 1983) or unitary representations (O’Malley & Draper, 1992). An example of a propositional if-then representation for Bilbo would be: *if* locked door *then* key required to open (Tolkien, 1937). Propositions are a prerequisite to the acquisition of schema (Jonassen, 1995). Schemata are static cognitive structures that involve networks of general knowledge or propositional representations (Johnson-Laird & Byrne, 1991; Kyllonen & Shute, 1989; Sasse, 1997; Redish, 1994). They, like Piaget’s (1970) schemes, are based on previous experiences that have been created through assimilation and accommodation.

Schemata are drawn on to help the individual to explain how propositional representations and/or items in the environment relate to each other (Kyllonen & Shute, 1989). If you walk into a darkened room you use a ‘light-switch’ schema to automatically reach for the location of a switch to turn on the light. Due to past experience the light switch can usually be found just inside the door frame of a darkened room. The networks, used to run this particular schema, are based on constantly-used, everyday experience. Networked schemata are created as related concepts, such as, the need for light and the location of the light-switch, are linked meaningfully by an individual. These networks involve categorisation, compartmentalisation, and networking of knowledge that make sense at an individual level but that also frequently replicate generic phenomena, such as the placement of everyday household objects.

Schemas are conglomerations of simpler sub-schemas often referred to as scripts (Kyllonen & Shute, 1989; Preece, Rogers, Sharp, Benyon, Holland & Carey 1994). For the students undertaking this robotic project, if downloading a program to the robot was a schema, then an example of a sub-schema or script would be one discreet section or action, such as loading the batteries into the robot to give it the power to function. The student would use previous experience of loading batteries in battery-operated toys to enable them to complete the sub-schema or script.

Useful as they are, many schemas are required to enable an individual to function in the real world. However, as in the example above where the robot did not follow the program as expected even with new batteries, or in Bilbo's case a regular key would not unlock a door, then an individual is faced with a problem for which existing propositional representations and schemata may be of little use. You would need other, less rigid cognitive resources to enable you to solve the problem. Merrill and Gilbert (2008) compared schema with mental models and concluded that while schema tend toward stability, mental models are transient. While schema are stable due to their reliability demonstrated through replication, mental models are a set of concepts "related together in a meaningful way in a holistic representation of the parts, relationships, conditions, actions, and consequences of a complete problem or task" (Merrill & Gilbert, 2008, p. 201). When mental models are run to solve a problem, they are modified or expanded to account for novel experience, that would involve an adaptation process that substantiates Merrill and Gilbert's (2008) analysis of their transience.

Norman (1988) also recognised that cognitive representations, such as schemata, did not explain what occurred when an individual encountered a new problem, such as using an unfamiliar robotic software system for which existing schema were ineffective. The inflexibility of schema theory did not enable negotiation of the irregularity of everyday encounters with the environment (Halford, 1993; Johnson-Laird & Byrne, 1991; Norman, 1988). Mental models use propositional representations *and* schema to predict outcomes (Kyllonen & Shute, 1989) and to constrain short-term memory overload (Henderson & Tallman, 2006) that would occur if a multitude of scripts or sub-schema were being used to find a solution to a problem. Complex problems, particularly, are limited by working memory as it cannot hold all the components, such as skills and knowledge, required to calculate a solution (Merrill & Gilbert, 2008). Schemas and associated skills, therefore, are a prerequisite (Jonassen, 1995) to mental models that require "the concerted exercise of multiple skills applied to elaborate schemata" (Kyllonen & Shute, 1989, p.132) to be constructed. Wild (1996) described mental models as a representation that provides a "mediating intervention between perception and action" (p. 10) enabling an individual to interpret, remember, and communicate what is already stored cognitively. The impact of mental model theory on communication is significant and has been studied vigorously by Johnson-Laird through his work with language comprehension and semantic reasoning (1983, 1986, 1989, 1991, 1998, 2004, 2006).

How one communicates through, and understands, symbolic text is important in classroom experiences. Johnson-Laird's (1983) early research focussed on mental models and language comprehension. Instead of using traditional, symbolic logic theories to explain human thought processes, he proposed mental models as the mechanism by which reasoning is explained with an emphasis on semantic rather than syntactic content. While individuals still use symbolic representation, such as decoding the class whiteboard, this occurs through translation of an external process into an internal one (Norman, 1983; Johnson-Laird & Byrne, 1991; van der Veer & Peurta-Melguizo, 2002; Vosniado, 2002). New symbols are derived from this interaction through inference and are translated into actions and predictions of external events through a reasoning process. During this reasoning process, the individual constructs functional mental models that are cognitive representations of the interaction with the environment (Johnson-Laird, 2004; Johnson-Laird & Byrne, 1991; Vosniado, 2002). The mental models incorporate the relevant semantic information of the phenomenon, the problem being encountered, and a solution (Goodwin & Johnson-Laird, 2008; Johnson-Laird, 1983; Johnson-Laird, 2004). Mental models are, therefore, much more complex than schemes (Piaget, 1970) or schemata (Anderson, 1977).

To Pitts (1994), mental models involved "cognitive constructions that are a network or web of related understandings" (p. 23). However, this definition does not address the cognitive processes that are undertaken when these "constructions" are run to solve unique problems. How an individual's understandings are related to each other is a question of personal meaning-making and may be constrained by social and cultural influences (Vosniado, 2002). Therefore, the relevance of language comprehension (Carley & Palmquist, 1992; Glenberg, 1997; Goodwin & Johnson-Laird, 2008; Johnson-Laird, 1983; Johnson-Laird & Byrne, 1991) helps relate the theory of mental models to that of embodied memory (Glenberg, 1997). Language, itself, acts as a substitute for some interactions with environmental phenomena, such as robots, and through these interactions mental models are created and run.

In order for the mental model to be effectual in sourcing suitable solutions, it should have a structure that is related to the objects or phenomena it represents. A one-to-one correspondence, within the co-structural relationship between the mental model and the phenomena, may help us understand what concepts can be easily associated due to the ease or otherwise with which they fit together. Glenberg (1997) found that some associations fit together very easily and enable concepts such as “spotted horse” and “spotted idea” to be linked together (p. 2). Cognitive structures, to which mental models are linked, are structural maps that can serve as conceptual structures that form the basis for understanding and reasoning (de Jong, 1988; Garnham & Oakhill, 1994; Halford, 1993).

It is relevant here to link the structure of mental models to the descriptors they have been given by various researchers. Halford (1993), in his seminal work on mental models, argued that a *representation* (i.e., a mental model) was a mapping from the item in the environment to the image in the mind. He described an *analogy* as a mapping from one of these internal, cognitive representations (i.e., a mental model) to another internal representation; a mapping that demonstrates some form of relationship. Thus, mental models are constructed from components that are taken from both the current situation in which the individual is placed and any analogies that may be embedded in mental models stored in long-term memory.

Researchers and theorists have created a variety of themes with a multitude of cognitive descriptors for mental models that go beyond mere definitions due to the woven fabric of functionality that mental models demonstrate to those working in the field. Mayer (1989) called mental models “conceptual” (p. 43) structures that include diagrams and/or words that help learners build mental models of a system under study. Newton (1996) also referred to them as “conceptual structures” or “homologies” (p. 208) that correspond to a phenomenon. This homologous descriptor might be contentious due to its definition of a correspondence that is similar in structure but not necessarily in function (Moore, 1987). It does, however, suggest a correlation that supports Johnson-Laird’s (1983) mental models that are seen to correspond to a situation and, through this correspondence attribute, enable understanding and problem-solving.

Halford (1993) argued that mental models reflect the structure of phenomenon in the environment whether it be a situation, event, task, problem, procedure, or a concept with which an individual is faced. He hypothesised that if we correctly or incorrectly understand the phenomena then we have a respective correct or incorrect mental model of it. In other words, individuals store mental models, that is, representations of phenomena that they correctly or incorrectly comprehend and for which they see some value in retaining.

Norman (1983) highlighted that mental models can be inaccurate and incorrect in nature. The inaccurate/functional nexus seems paradoxical. Yet it is precisely this paradigm that makes defining mental models similar to trying to answer a Hobbit riddle: "A box without hinges, key, or lid, yet golden treasure inside is hid" (Tolkien, 1937, p. 71). Senge (1992) highlighted the multifarious nature of mental models by explaining that we "cannot carry all the complex details of our world in our mind" (p. 36). He completed this intricate picture by arguing that ". . . we do not have mental models . . . we are our mental models" as "they are inextricably woven into our personal life history and sense of who we are" (p. 37).

There is a substantial volume of empirical research (Goodwin & Johnson, 2008; Halford, 1993; Johnson-Laird, 1983, 2004; Merrill & Gilbert, 2008; Newton, 1996; van der Veer & Peurta-Melguizo, 2002; Vosniado, 2002) that has contributed to the view of mental models as internal representations, cognitive structures, or conceptual states created by individuals in their responses to interactions with phenomena in the environment. The essence of mental model theory is its capacity to explain how individuals interact with the world.

The discussion of mental models becomes more complex when an individual's interactions with a system are considered. Williamson (1999) proposed that mental models allow users of systems to operate on, and within them, without having a complete conception of the system due to mental models being made up of concrete examples and procedures as well as abstract theories and relationships. In other words mental models may be incomplete (Johnson-Laird, 1983; Norman; 1983), have limited stability, and can be parsimonious (Norman, 1983) but they are useful.

Williamson (1999) also proposed that mental models are malleable and require some accommodation by the user or learner and that this may not always be easy to do, particularly if it is anchored by deeply held beliefs (Norman; 1983). Social and cultural relationships (Vosniado, 2002) that anchor a mental model may be very strong due to their being based on experiences and personal perceptions as well as superstitions that may attach to certain emotions and/or experiences. The outcome of this bimodality has a dual implication for teaching: the social and cultural relationship can make mental models difficult to manipulate and alter, but the strength of individual perception can also serve to make learning more rich and memorable.

The Nature of Mental Models

A Question of Process and Product

The nature of mental models as a *process* was explored by Henderson and Tallman (2006) who referred to them as "a mechanism that functions to help us understand, as well as act in, and on, the world" (p. 25). Mental models enable complex calculations to be completed (Rouse & Morris, 1986; Seel, 1995; Stripling, 1995) through their retrieval from long-term memory and manipulation in short-term memory (Anderson, Howe & Tolmie, 1996; Johnson-Laird, Girotto & Legrenzi, 1998; Newton, 1996; Power & Wykes, 1996). Mental models draw on the conceptual (Henderson & Tallman, 2006), declarative, and procedural knowledge (Barker, van Schaik, Hudson, & Meng Tan, 1998; di Sessa, 1986) by which solutions to problems are predicted, enacted, and resolved in short-term memory (Anderson et al., 1996; Glenberg, 1997; Power & Wykes, 1996).

Once run, however, the mental models themselves are then stored in long-term memory for future use (Canas & Antoli, 1998; Gentner & Stevens, 1983; Henderson & Tallman, 2006; Norman, 1983). This substantiates their existence as a *product* that can be re-activated in the future. Newton's (1996) work in science focused on the *product* nature of mental models albeit with the premise that mental models are not inert products. What he proposed was that the process of creating the relationships between elements of information requires the product of the mental model to be formulated or retrieved and enacted in order for the inferences, predictions, and decision-making required to understand and act on environmental phenomenon. The execution of the decision-making process requires a product — a mental model — to be created or retrieved, articulated, manipulated, tested, and transformed in order for understanding, comprehension and/or problem-solving to occur.

So, this activation or "running" (Carroll & Olson, 1988; Cohen, Thompson, Adelman, Bresnick, Tolcott & Freeman, 1995; Halford, 1993; Haycock & Fowler, 1996; Henderson & Tallman, 2006; Norman, 1983; O'Malley & Draper, 1992) of the mental model *product* is a *process*. This results in a restructured mental model product that is then stored for later retrieval and processing.

The process nature of mental models is seen as being not just a mental state or representation to be built and maintained but also as a platform for decision making and taking action (Williamson, 1999); that is, a personalised work bench for experimenting with phenomena. As Norman (1983) stated, mental models "are what people really have in their heads and what guides their use of things" (p. 12). Wild (1996) referred to the mediation process of mental models and how they provide a representation that, in turn, provides the means by which an individual can "interpret, remember, and communicate information" and control their performance (p. 10). Henderson and Tallman (2006) discussed how the fluidity and autonomy of mental models have reciprocal consequences for both the task for which they are being used and the mental model itself. Mental models are both a process and a product similar, in a way, to how a student constructs (process) a robotic construct (product).

The process nature of mental models is, therefore, associated with how they are run (Henderson & Tallman, 2006; Johnson-Laird, et al., 1986; Norman; 1983; Payne, 1991) to find answers to problems. This act of running and problem-solving was evident in this project when the robot did not move in accordance with the program's instructions. Sam, one of the participants, was required to run several mental models to find a solution to the problem (Chapter 5). This "runnability" is a core defining function of mental models. Needless to say, it is an action where the mental model, inert when stored as a product of cognitive activity, is activated or 'run' as a process to test possible outcomes in response to environmental phenomena. The act of running (Johnson-Laird, et al., 1986; Norman, 1983; Payne, 1991) a mental model converts dormancy into action because new ideas or images are created (Henderson & Tallman, 2006) within the mental model as it works on the external phenomena.

Problems, too, were the constant companions of our friends in *The Hobbit*. But, Elrond, the Elf King, gives the journeymen a cryptic clue that becomes part of the mental model that Bilbo Baggins calls on later to open the door to the Lonely Mountain: "'Stand by the grey stone when the thrush knocks,' read Elrond, 'and the setting sun with the last light of Durin's Day will shine upon the key-hole' " (Tolkien, 1937, p. 51). Similarly, the students involved in this study were faced with unlocking clues and interpreting symbolic language as they ran their existing mental models to navigate through the robotics experiences. Mental models, therefore, should have several functions in order to be useful.

The Multiple Functions of Mental Models

A Question of Unravelling Problems

Individuals construct idiosyncratic yet functional mental models (Norman, 1983). This uniqueness arises from the way in which a mental model reflects an individual's personal interactions with others, the environment, a situation, a task, procedure, concept, or phenomenon (Halford, 1993). Mental models also contain reflections of problems, events, and stories that are imaginary (Byrne, 1992). They arise from our constant interaction and complex experiences with the world and the idiosyncratic ability to develop the relationships and dialogue necessary to guide our understanding of such interactions and experiences. Mental models have multiple functions that enable numerous environments and problems to be explored.

Explanatory Function

Mental models have an explanatory function as they "facilitate cognitive and physical interactions with the environment, with others, and with artefacts" (Henderson & Tallman, 2006, p. 25). Johnson-Laird (1983) succinctly outlined the explanatory function of mental models:

> understanding certainly depends on knowledge and belief. If you know what causes a phenomenon, what results from it, how to influence, control, initiate, or prevent it, how it relates to other states of affairs or how it resembles them, how to predict its onset and course, what its internal or underlying "structure" is, then to some extent you understand it. The psychological core of understanding, I shall assume, consists in your having a "working model" of the phenomenon in your mind. If you understand inflation, a mathematical proof, the way a computer works, DNA or a divorce, then you have a mental representation that serves as a model of an entity in much the same way as, say, a clock functions as a model of the earth's rotation. (pp. 2, 3)

Simply put, in order to understand the world "human beings construct models of it in their mind" (Johnson-Laird, 1983, p. 3). Mental models that are perceived to be of use by an individual will be stored within an idiosyncratic network. They have personal relevance for future interaction with, and understanding of, phenomena. Mental models enable understanding (Gentner & Stevens, 1983; Johnson-Laird, 1983; Newton, 1996) because, if

> you know what causes a phenomena, what results from it, how to influence it, control, initiate, or prevent it, how it relates to other states of affairs or how it resembles them, how to predict its onset and, of course, what its internal or underlying nature is (Johnson-Laird, 1983, p. 81),

then you understand it.

This is not to say that the understanding that individuals have represented in their mental models is complete or accurate. Indeed, as Norman (1983) advocated, an individual's mental models are constrained by personal attributes, such as their background experiences, expertise in different domains and, often, their unscientific or superstitious beliefs. People forget things and mental models that are not used regularly become stagnant (Norman, 1983), often needing re-evaluation and modification if they are to remain useful and functional as a means of explaining phenomena.

Predictive Function

Mental models are individual and idiosyncratic (Norman, 1983) but they have to be functional as they are being constructed (Cronje & Fouche, 2008; Henderson & Tallman, 2006; Norman, 1983) as well as functional in facilitating the investigation of alternatives as a learner explores, for example, a robotics problem or encounters new real world phenomena (Carley & Palmquist, 1992; Renk, Branch & Chang, 1994).

One of the purposes of mental models is to enable an individual to predict how a system will work or a problem will be solved (Johnson-Laird, 1983; Norman, 1983). Prediction serves to differentiate mental models from other cognitive structures such as plans, lists, and schemas that do not account for novel situations individuals encounter (Halford, 1993; Schwamb, 1990). The more accurate and complete the mental model, the more predictive power it provides to develop and guide possible scenarios suitable to the situation such as constructing a robot.

Learners will be motivated by different needs and desires and mental models that are functional for one may be unworkable for another. It is important to recognise this individualisation within the classroom, because one of the roles of mental models is their power to predict an outcome of various actions that are possible during an interaction (Bibby, 1992). It would seem that the search for solutions usually requires learners to concurrently run and link various mental models (Johnson-Laird, et al., 1986; Norman; 1983; Payne, 1991) as they predict possible outcomes. Johnson-Laird (2006) reported that the most plausible explanation for the selection of an erroneous predicted solution lies in the learner's inability to consider all alternative solutions. Vosniadou (2002) also recognised the predictive power of mental models, particularly in the study of science, but suggested that learners will usually only run one mental model to perform the predictive function in seeking solutions or answers to questions.

However, it would seem that multiple mental models or parts of mental models can be run simultaneously (Johnson-Laird, et al., 1986; Norman, 1983; Payne, 1991), thereby enhancing the usefulness of prediction in problem-solving. The linking of related parts of mental models that are deemed useful by the individual depends on the network of related understandings (Henderson & Tallman, 2006; Pitts, 1994) that are instantiated when an individual creates mental models. How well the appropriate mental model or part thereof is accessed or retrieved, when required, will depend on the efficacy of the storage process and the relationships the individual perceives as relevant and useable.

Once activated, any mental models that prove ineffectual can be discarded or manipulated and refined in order that a workable solution is found. Holyoak (1991) explained that the expertise individuals have in completing complex tasks is due to their ability to switch among alternative functions that are embedded in the various mental models that are run simultaneously. Although, this switching may or may not be a conscious act (Nelissen & Tomic, 1996) but mental models enable a person to anticipate, or predict, an outcome of a chosen solution or action in solving a problem (Norman, 1983).

Control Function

Mental models control behaviour (Henderson & Tallman, 2006; Newton, 1996) or action due to their purposeful function for option selection when individuals are faced with choice. Williamson (1999) argued that mental models (a) act as a platform for making decisions, problem solving, and taking action and (b) control cognitive and physical behaviour. The control function of mental models held by teachers was identified by Henderson and Tallman (2006) during teachers' interactions with students who were undertaking computer searches. Teachers can be conscious of running mental models, particularly in an activity where new concepts, such as using search engines, are being presented. However, being conscious of running the mental model does not preclude that act of running a mental model from happening automatically. If students are struggling to understand a concept, teachers retrieve and run mental models containing ideas, concepts, and/or strategies from past lessons that were successful. Such retrieval of successful experiences, by the teacher, indicates that mental models can be controlled to adapt the environmental phenomena and, subsequently, enable the successful scaffolding of the new knowledge to existing concepts (Vygotsky, 1978).

This study uncovered how mental models can control behaviour, particularly how it may prove difficult to alter such a mental model even if an individual becomes conscious of how it might be negatively controlling their behaviour (Chapter 7). A subjective explanatory value can be attached to mental models (Seel & Strittmatter,

1989) because it may be difficult to abandon or manipulate a mental model unless it is disproved by influential perceptual data that is obviously inconsistent with previously held knowledge and concepts.

The running of mental models enables performance, even a poor one, to be controlled because mental models, as opposed to other cognitive structures such as schemata and scripts, have the capacity to deal with novel situations that may disturb the effective execution of a schema. Classroom experiences, documented by Henderson and Tallman's (2006) research, were found to be either "liberating or stultifying" (p. 25). The difference is due to either the individual controlling their mental models by adapting them when they proved ineffectual or the individual being controlled by unadaptable mental models that did not facilitate an effective solution.

The important function of control reinforces the perception of mental models as both processes and products because, as Newton (1996) asserted, an individual must be willing to articulate and restructure their mental model in problem situations. This significant call to adapt an ineffectual mental model requires an individual to recognise, and then instantiate, the necessary blend of knowledge, beliefs, metacognition, and control. Mental models must be generative (Newton, 1996) in order to create understanding and, in turn, new mental models. The product enables the process that produces the product.

Diagnostic Function

The diagnostic function of mental models for students relies on an understanding that students may be working with mental models that do not allow them to assimilate new concepts (Royer, Cisero & Carlo, 1993) without guided assistance. For example, during the teach-back experience (Chapter 7) Jayne was prepared to advance her pupil to a second program before she had understood her own programming errors and had synthesised the problem in the first program. Jayne's mental model diagnostic functionality was inadequate to the task.

Ritchie, Tobin and Hook (1997) used the term "perturbation" to explain contradictions where new knowledge will link with prior knowledge to create a modified mental model. This customised mental model will incorporate the new experiences and concepts in order to overcome the perturbed state. Guidance may be necessary for the learner to move through perturbation into a state of equilibrium

(Piaget, 1970). This need for guidance reflects Vygotsky's (1978) emphasis on the Zone of Proximal Development where it is important to take, with scaffolded support, students "a little beyond" (p. 8) what they know or are comfortable with in order to create authentic learning situations.

Mental models play an essential role in enabling this diagnosis function whereby students develop rich and robust metacognitive awareness, particularly in new domains of learning. Kyllonen and Shute (1989) recommended that process-outcome predictions for assessing mental models be implemented to enable the students' ineffectual mental models to be diagnosed during the performance of some task. Mental models are internal representations that are "exteriorised" (Barker, van Schaik, Hudson, et al., 1998) or externalised through some action. The implication follows that teachers would need to be quite clear about what behaviours or actions are required to be externalised to constitute the adequate performance of a task. The students' performance of those tasks would determine the quality of the mental model/s being run by the individual. Instructional intervention may then be required to guide the learner to modify an inaccurate or ineffective mental model.

A mental model's diagnostic function (Royer et al., 1993; Williamson, 1999) for a learner is closely associated with their communication function as they allow what an individual knows to be communicated to others and then analysed for accuracy and effectiveness. In mental model theory, it is the mental model that enables a student to communicate their perceptions because the predictions of the effectiveness of actions and reactions can be demonstrated so that any misconceptions or gaps in knowledge can be corrected (Williamson, 1999).

Communication Function

Mental models play an important role in the communication processes of writing, reading, talking, and listening while thinking through problem-solving situations (Barker, van Schaik & Hudson, 1998). The act of sharing or communicating our mental models to others usually involves oral or written discourse (Craik, 1943; Johnson-Laird et al., 1998). Oral discourse entails discussion where the social negotiation of a transitory mental model can jointly be held by the participants in the dialogue (Anderson, et al., 1996). Written discourse involves writing where text or symbolic script is used to express what is known (Barker, van Schaik & Hudson, 1998). The richness of the diversity, with which the communication function of mental models is exhibited, guided the methodology of data collection for this study as surveys, different interview techniques, teach-back episodes, and journals were used to exteriorise the mental models of the participants.

Oral sharing may involve the “collaborative critiquing of one’s own and others’ mental models” (Henderson & Tallman, 2006, p. 47) where mental models are communicated through language and other individual and cultural nuances, such as facial expression, body posture, and vocal shades. The diversity of such non-verbal communication traits were exhibited during the focus group interview in November 2005 (Chapter 7) where students lounged in their chairs during the interview, indicating a relaxed and comfortable mien during the interchange of ideas. When these and other students share ideas, transitory models are run briefly in working memory (Preece et al., 1994; Williamson, 1999). Participants in such exchanges negotiate and manipulate the many mental models that are required both to transverse the problem situation and to participate in a useful discussion (Barker, van Schaik & Hudson, 1998; Nersession, 2007) of the relevant issues.

There may be some constraints on the effectiveness of such transitory mental models being processed into more permanent mental models in long-term memory (Anderson et al., 1996). Analogy (Gentner, 1998) can be used to improve effective communication, particularly in introducing new ideas for which learners do not hold mental models or hold inaccurate mental models.

Analogy (Gentner, 1998; Halford, 1993; Johnson-Laird, 1983; Newton, 1996; Young, 1983) can be used to communicate concepts to others through the use of the transferable characteristics of the analogy to the concept or problem being discussed. An analogy usually involves mapping from a particular source structure to another that may be called the target (Newton, 1996) and that shares attributes that are useful to the learner. The relational links made by using analogy strengthen the network of related meaning by anchoring similarities of the new mental model to analogous structures within existing mental models.

Another useful device that involves the communication function of mental models is graphical representation. Doyle, Radzicki and Trees (2008) established that a variety of diagrams and matrices were used by researchers to represent and facilitate change in mental models. Williamson (1999) used concept maps to exteriorise the mental models of pre-service teachers because they offered a graphical representation of the ways an individual arranges, names, and connects concepts within a domain.

Jonassen, Beissner and Yacci (1993) saw concept maps as being able to incorporate knowledge and concepts in relational drawings that clearly identified relationships between concepts through the incorporation of multiple labelling. Enger (1996) found that concept maps used to communicate mental models empowered students in both learning and assessment due to the constructivist nature of the process that reflected Novak's (1990) seminal work on concept mapping. Ahlberg (2008) supported the use of concept maps to examine the mental models of learners because they can reflect both the type and level of knowledge held.

Chang (2007) found that students were able to express their mental models on abstract ideas by drawing concept maps while being interviewed. A subsequent study by Novak and Cañas (2008) found that concept maps may also be used for the assessment of student understanding and Ahlberg (2008) confirmed that the mental models of both novices and experts alter the mental models expressed in concept maps as more knowledge is gained.

Concept maps were not used as data collection tools in this study because other instruments, such as journals, various types of interviews, teach-back and questionnaires, afforded the participants greater opportunity to express themselves in the diverse ways required to gain a rich appreciation of their espoused, in-action, and reflective mental models longitudinally. They were also not used as an assessment tool by the teacher as this would have involved numerous lesson periods to teach students the mental models to do this properly.

Memory Mechanism Function

The bimodal process-product existence of mental models is demonstrated by their transience in short-term memory and permanence in long-term memory (Bagley & Payne, 2000; Hambrick & Engle, 2002; Mani & Johnson-Laird, 1983). The running of a mental model can be influenced by the student's ability to utilize their working memory effectively for that situation (Anderson et al., 1996; Johnson-Laird et al., 1986; Newton, 1996; Power & Wykes, 1996).

Sam had success in negotiating a challenging problem-solving situation in the second stimulated recall sessions in July 2005 (Chapter 5). He ran several mental models as he compared the effectiveness of the various strategies by predicting the likely outcomes of each strategy in turn. His working memory was able to retrieve the appropriate mental models and incorporate new knowledge of the robot/program configuration to solve the problem.

The function of the memory mechanism in mental model theory is, therefore, fundamental. The process of retrieval, adaptation, and subsequent re-storing distinguishes this form of cognitive structure from others (Canas & Antoli, 1998; Carroll & Olson, 1988; Halford, 1993; Newton, 1996; van der Veer, Chisalita & Mulder, 2000). Canas and Antoli (1998) proposed the basic hypothesis of mental models as dynamic representations that are created in working memory by combining information from existing mental models stored in long-term memory and environmental characteristics relevant to the problem at hand.

Anderson, Tolmie, Howe, Mayes and Mackenzie (1992) explored the effectiveness of working memory and how its capacity does not increase with age or with cognitive development. The efficient use of working memory means that practising tasks that require the manipulation of mental models has occurred. This practice strengthens the links that relate the information into meaningful chunks that can be used in working memory and subsequently stored in long-term memory. Chunking related knowledge enables many discrete units of information to be grouped for operational activity and relational storage. Miller’s (1956) seven plus or minus two pieces of discrete information is a clear guide to the operational and storage capacity of short-term memory. It also demonstrates that practising how to link information meaningfully into chunks can make students more adept at problem-solving.

Memory load.

The load on working memory can be minimised by constructing mental models of what is “true” as opposed to what is “false” (Johnson-Laird, 1983). While mental models can be inaccurate, we do not tend to store representations of perceived falsity (Goodwin & Johnson-Laird, 2008; Johnson-Laird, 1983, 2006). Because the mental model holds what the learner believes to be perceived truth, it enables learners to move forward positively armed with greater validity about their suppositions about the solution to a problem. This is an important point for teachers to note when considering the valuable role mental models play in a learner’s cognitive development.

Halford (1993) discussed the difficulty for young learners to efficiently use working memory to complete difficult tasks if the number of processing steps and sophistication of the concepts were high. The working memory storage load influences the ability of the learner to hold unfamiliar concepts in working memory while manipulating them to find solutions. If mental models are inaccurate or stagnant (Halford, 1993) and require modification and re-evaluation, then the load on working memory and cognitive capacity needed for solving problems or negotiating responses to tasks is challenging for young learners. What may make a problem more difficult to deal with is the very nature of the environment in which the problem-solving is taking place, such as a busy school computer or robotic laboratory. The need to negotiate the environmental stimuli, including working with a partner or partners, while simultaneously addressing the problem stimuli can challenge the capacity and subsequent efficiency of working memory for many learners (Power & Wykes, 1996).

Patterning.

Mental models have been proposed as a memory retention device (Williamson, 1999) due to their role in aiding retention through relating concepts in and across domains via the use of devices such as patterning. Patterning can aid memory retention in both simple and more complex tasks. Viewing the pattern of the icons on the screen in the Robolab™ software became memorized through repetition evidenced by Jayne who "just usually click and click" her way through the program (Stimulated Recall Interview, 15 July 2005). Indeed, Rouse and Morris (1986) discussed experts' mental models and how a "highly developed repertoire of pattern-oriented representations" (p. 35) can be stored in long-term memory in robust mental models.

How efficiently the storage of mental models is organised may depend on the relationships an individual makes as they create knowledge. If they link many mental models together with connections based on analogy, chunking, and patterning, for example, the links may be strong due to the meaningful use of conceptual, declarative, and procedural knowledge. Therefore, strong links among chunks will enable more rapid retrieval and manipulation in working memory of the information required to experience success in problem-solving.

Summary of the Multiple Functions of Mental Models

This section approached the process/product question of mental models by exploring their many functions. Their *explanatory* function enables understanding and selection of strategies. Their *predictive* function enables problem-solving in novel situations with the *control* function providing a platform from which to make decisions. The *diagnostic* function enables an understanding of how perturbations can lead to real learning while the *communication* function enables others to see and understand the externalisation of mental models. Mental models are both transient and permanent because of their existence in both working memory and long-term memory as constructs of knowledge retrieved and created in relation to the individual's interpretation of phenomena within the environment. Learners' memory load can be minimised by introducing strategies, such as patterning, that aid memory retention.

This study of the multi-dimensional and multi-functional nature of mental models becomes even more of a fascinating journey when contextualised in a classroom where mental models are being constantly created, shared, questioned, refined, and challenged, particularly in a discovery-type environment of robotics.

Robotics and Mental Models

A Problem-Based Learning Environment

Our cultural tendency to personalise inanimate objects, such as machines (Kiesler & Goetz, 2002), often by giving them names (my pink-covered research journal is "Pinky") may encourage the development of strong anthropomorphic mental models when we interact with robots, androids, and other non-human phenomena. This readiness to humanise or personalise phenomena may be an example of cognitive processing that Hintzman (1986) saw as necessary to integrate new knowledge and experiences with known or familiar structures.

Different images are necessary for exemplar-based processing (Linville, Fischer & Salovey, 1989) that can occur when separate images are linked or joined to create a consistent or acceptable anthropomorphic mental model (Keisler & Goetz, 2002) of a non-human phenomena. Keisler and Goetz (2002) gave a "cheerful robot" as an example of this type of processing where a "life-like robot that tells a joke could activate . . . exemplars of . . . machines and . . . humorous people" (p. 1). The "humanlikeness" of a robot, through either its behaviour or appearance can, they believe, "lead to a mental model that does not deny the technology in the machine but that also incorporates anthropomorphic features into it" (Keisler & Goetz, 2002, p. 2).

The robots the students were using shared more features with a remote-controlled car than a humanistic automaton and would not engender strong anthropomorphic mental models (Edwards-Leis, 2010). The participants, while ignorant prior to the activities as to the design of the robots with which they would be interacting, were not dissuaded from active involvement once they began constructing their first 'robotic brick' from the Lego™ Dacta kit (Edwards-Leis, 2010). While their anthropomorphic mental models would be of interest, they were not a fundamental part of this inquiry. What was significant were other studies into middle years students' mental models of robotics that had used either the Lego™ Dacta kits or equivalent simulation software. Few were found. Some studies focussed on the mental models of robotics with simulation software (Eronen, Jarvela, Roe & Virnes, 2002; Miglino, Lund & Cardaci, 1999), while others (Barchi, Cagliari & Giacopini, 2002; Bilotta & Pantano, 2000; Kennedy & Trafton, 2007; Kiesler & Goetz, 2002; Resnick, 1989, 1994) involved the non-computerised construction of robots using a variety of materials. None of the surveyed research endeavoured to conduct a longitudinal study that involved the investigation of participants' mental models after experiencing hands-on robotic construction and programming over a twenty month period.

This dearth of research is due to the very nature of the equipment, its dependency on time and money resources and its problematic nature; breakdowns are frequent and the time and equipment necessary to design, build, program, and test a robot in reality appear to be far beyond the confines of a research project, let alone a classroom teacher. This study was possible due to the willingness of the teacher and students to deal with, and overcome, those limitations. How else can students learn to negotiate an authentic learning situation if they are precluded from experiencing the very frustrating, unpredictable realities that often accompany conventional challenges?

Kennedy and Trafton's (2007) study looked at the shared mental models of members of a team who were building a robot to complete a certain human-robot interaction. The plausibility of the design required for such interaction is of great interest as Kiesler and Goetz (2002) discovered when they studied the mental models of people who design what they know is a machine but that, nevertheless, exhibits humanlike behaviour. Eronen et al. (2002) worked with children aged 10 to 14 in Kids' Club, a group coordinated by a Finnish university, and focussed on using simulation software. They selected such an environment because it would enable participants to "construct the mental models of robots and their tasks without being distracted by real-world problems such as non-working connections between the robot and the computer being used to program it" (p. 1). Such removal from the realities of the physical world of wires, batteries, computer components, and Lego™ does not enable a realistic appreciation of how thinking and mental models need to change (Miglino et al., 1999) when operating in a "real" world as opposed to a "replicated" one.

Barchi et al. (2002) summarised the benefits of hands-on experience appreciably when they observed that, during their study, they were

> dealing with subjects [robots] that are 'autonomous' and animated, not so much because they are capable of physical movement in the space but, rather, because they are experienced by the children in a dimension of metaphorical recognition of life, and are therefore full of emotions and 'affective' involvement. (p. 21)

Similarly, the nexus between mental models and robotics provided a discovery-based environment for this study that was rich in cognitive, social, and affective interactions generating insightful implications for teaching, learning, and assessment.

In this study, while the students were experiencing constructionism (Papert, 1991) in the truest sense because they were building their own robotic constructs within a very specific context of learning, the generalised philosophy that underpinned their explorations into problem-solving was constructivism (Piaget, 1970). While the interpretation of their explorations may be more pragmatic because of their focus on a specific technology, their ability to generalise their experiences to other areas of learning was explored and is of immense value to the study of mental models. Robotics was the context within which mental models were being studied.

Papert (1980), in his seminal text, *Mindstorms,* discussed the transformation of learning when children learn to program because their learning becomes "more active and self-directed" (Papert, 1980, p. 21) when the knowledge they acquire is for a recognisable personal purpose. This is the central precept of constructivist pedagogy, where purposeful learning occurs when information and procedures are delivered but knowledge is constructed by the learner individually (Derry, 1996; Duffy & Jonassen, 1992; Moshman, 1982; von Glaserfeld, 1995) or, as part of a social constructivist environment (Anderson, Reder & Simon, 1997; Smagorinsky, 2001; Vygotsky, 1978), where collaboration within a student's Zone of Proximal Development (Vygotsky, 1978) enables them to construct meaning. This pedagogical shift is from one that is behaviourist (Merrett & Wheldall, 1990; Skinner, 1984; Sulzer-Azaroff, 1995) where students learn in order to avoid negative feedback to one that is process or constructivist oriented (Bilotta & Pantano, 2000; Conway, 1997).

The methodology of building, testing, evaluating, and altering a robot's behaviour requires an "experimentally driven design" (Bilotta & Pantano, 2000, ¶ iii) approach by the students. This approach involves the creation and/or retrieval and manipulation of mental models by students to accomplish each goal set for the robot. Resnick (1989; 1994) discovered that more creative solutions of robot programming to achieve a pre-determined goal were developed by students, particularly where the tasks were complex. Therefore, designing complex robotic programming challenges are beneficial for real learning where students are exposed to repeated opportunities to "re-launch" problem-solving mental models (Henderson & Tallman, 2006, p. 27) so as to critique their reliability in order to determine whether they should be kept or discarded.

The study of robotics offers a problem-based, learner-centred, and purposeful learning environment where the students can construct their own meanings (Jonassen, 1995). Students can also develop functional mental models (Norman, 1983) that provide them with the choice of possible actions during the interaction (Bibby, 1992). They should learn how a complex system operates by holding better mental models that are able to provide causal explanations (Milrad, 2002) and predict actions for the robot's behaviour as well as explain the changes in programming or construction that are required for the desired action.

Assessment and Mental Models

A Question of What and How to Measure

If mental models contain all of the interrelated elements of conceptual, declarative, and procedural knowledge (de Jong, 1988; Garnham & Oakhill, 1994; Halford, 1993; Merrill & Gilbert, 2008; Newton, 1996) that we know about the world, then having a clear picture of those mental models relevant to a particular topic should inform the teacher of a student's current state of cognition and the subsequent changes that occur during a learning experience. Nonetheless, it may not be that simple to gain access to the introspective mental model that is harnessing the knowledge required for learning to take place. While some researchers preferred to engage their research participants in a graphical representation of their mental models (Jonassen et. al., 1993; Novak, 1990; Williamson, 1999), the verity of their externalization does not necessarily mean that its form will provide fluent interpretation let alone measurement.

Perhaps, such pursuit of a visual representation of a mental model emanated from Craik's (1943) terminology - "small scale representation" (p. 12). This descriptive phrase, that suggests the interrelatedness of knowledge at an intrinsically individualistic level, may also have prompted the proposition that to measure such a phenomenon would require a graphical structure not dissimilar to that proposed by the mental model itself: a model of the mental model.

There has also been some discussion about the purpose of using such diagrammatic representations that, in authentic application, can actually facilitate changes in the mental models themselves (Doyle et al., 2008) rather than extradite some formative assessment information about the cognitive changes occurring within them. So are teachers, in essence, searching for a "one-size-fits-all" methodology of assessing cognitive change that can be used, not in conjunction with other strategies, but as a singular focus that has the capacity to encapsulate the cognitive movement that signifies learning? Or are they requiring additional evidence to build up a case upon which professional judgment can rest?

How does an understanding of how mental models function contribute to a discussion of the assessment of the cognitive changes that occur in learning? Literature suggests that the jury has not quite convened. While there is no conjecture as how mental models contribute to the teaching, learning, and assessment equation (Goodwin & Johnson-Laird, 2008; Stripling, 1995; Vosniado, 2002), there is no definitive solution to a possible rubric-isation of mental models for simple application in the classroom. This study aims to answer the question about how mental models can best be instantiated in a technology-based learning experience so as to provide clear evidence of cognitive change. However, it does not provide a universal solution to the perennial question of contextualized, authentic assessment strategies. Indeed, there seems to be no "one-size-fits-all" on the racks of possible assessment approaches.

The assessment strategies used by teachers should involve gathering information about students and their capabilities rather than a focus on grading students (McLaren, 2007; Wilks, 2005) to meet mandated systemic requirements. Eisner (1998) questioned the fragmentation of testing unit-based segments of learning and the ability of such an assessment regime to determine students' deeper levels of understanding. McLaren (2007) and Wilks (2005) also questioned such standardised testing as being capable of really enlightening teachers as to what is going on in students' minds, that is, in their mental models. Studies (Chervin & Kyle, 1993; Kimbell, 2002) comparing standardised test results and class performance, demonstrated that the skills used to reason through the written tests revealed only a small portion of the students' ability and failed to enable rigorous interpretations of students' responses. Chervin and Kyle's (1993) work showed that students "can justify wrong answers" (p. 20), and that standardised written tests also do not afford credit for complex reasoning skills. Wade (1999) summarised this point precisely by stating that "grade distribution does not tell an outsider what the student knows" (¶. 8). Importantly, Newmann, Secada and Wehlage's (1995) research found that a strong emphasis on testing within a classroom can lead to low levels of engagement by students. When a teacher invests time to engage students in well-designed activities, such as robotics, only to de-motivate them with rigid assessment strategies, then it is time to rethink practice. Authentic assessment does not de-motivate; it does inspire expressions of learning.

Inflexible assessment strategies, such as those engendered through restrictive, mandated standardised testing regimes are often used to judge the journey of learners. There is concern with this practice, particularly in areas of the curriculum such as Design and Technology, where the ability to be flexible and to respond creatively to uncertain outcomes is of more value to the learner (e.g., Atkinson, 2000) than the ability to follow a formulaic, recipe approach to task completion. Teachers are under a great deal of pressure to conduct assessment that meets systemic requirements for reporting to interested parties at particular intervals. In Australia, parents, guardians, and carers are given data on their child's progression through the curriculum at a school, region, state, and national level (Freebody, 2005) and the community can access this comparative testing data from a national website. Kimbell (2002) described such assessment practice as being a hurdle; the leaping of which rewards the implementation of such instruments that follow traditional and safe strategies to evaluate student progress. He emphasised that an important element of assessment practice involves the determination of how a student accesses the knowledge and skills required at a specific time so they can complete a task; in effect, how they activate their mental models (Stripling, 1995).

Flexibility, it would seem, could be applied to the timing as well as the structure of the assessment design. Formative assessment has long been attributed to effective teaching practice due to its ability to inform teachers and learners of the progress being made and the areas of learning that still require attention (Matters, 2006). Nevertheless, summative assessment, that provides "end of course currency" (McLaren, 2007, p. 11), continues to be more rigorously discussed, promoted, and subsequently used to determine benchmarks of attainment. This reliance on inappropriately-timed assessment can limit learning efficacy due to a teacher's skewed focus on gathering summative data, testing, and reporting (Broadfoot & Black, 2004) rather than on teaching and learning. Project-based explorations, such as robotics, that engage and challenge students' mental models for problem-solving, promote learning efficacy because they avoid the measurement of misconceptions (Hoese & Casem, 2007) evident in summative assessment strategies.

Curriculum documents are designed to define learning experiences that equate to capability at particular levels as well as the types of opportunities teachers should construct so as to advance desirable, pre-determined skills. Assessment strategies are sometimes included in the syllabus documents, often in modular form, and relate specifically to a unit of content. Teachers contextualise the content to engage the learners in activity that is of interest and relevance to their lives. This does not confer a similar relevance to the assessment strategies used to measure attainment of the content.

Teachers establish how they are going to assess learning when they develop their curriculum plan. Systemic pressure to produce evidence of student progress through the levelled curriculum may encourage a teacher to design simplistic, ritualised testing or evaluation strategies that may involve a narrow view of assessment that subsequently may only focus on a narrow view of learning. In 1998, Givens warned about the nature of assessment tasks that address this narrow view because their rigidity actually may stifle creativity rather than develop opportunities for the celebration of the learning journey. Teachers who motivate through creative curriculum design may unwittingly contribute to stifling that very creativity by incorporating narrow assessment strategies. Assessment tasks often ignore the very application of creative problem-solving and the appropriateness of mental models to solve problems (Glaser, Lesgold & Lejoie, 1985) that the tasks are designed to measure. Murphy and Hennessy (2001) promoted authentic school assessment strategies that establish such authenticity by an added focus on the personal and cultural aspects of students. This involves strategies that revolve around the students themselves and their lives outside school. Authentic assessment incorporates "relevant and useful knowledge, thinking and practical skills" (Matters, 2006, p. 31) to involve students in generating mental models about their learning progress.

If assessment strategies are to be authentic and if they are to "probe and record chronologically the pupil's thinking" (Barlex, 2007, p. 53), then they require a connection to how the student constructs their mental models of the success of their actions (Dorst & Dijkhuis, 1995). Barlex (2007) proposed that such probes require students working individually, in pairs, and/or in groups that are guided by teachers. This would enable assessment for learning to be instantiated in the curriculum rather than the production of simplistic, systemic assessment of the content. This coordinated effort requires communication between all parties to truly authenticate and, indeed justify, the assessment experience.

Distributed Mental Models

A Question of Sharing

Personal constructivist (Bruner, 1974; Piaget, 1970) and social constructivist theory (Vygotsky, 1978) propose that an individual's conceptualisations and creation of cognitive representations derive from internalising experiences with the environment and/or with others. The synergistic act of sharing our mental models could result in shared mental models that may be superior to any individual's mental model (Anderson et al., 1996). Indeed, students can become very astute at finding, within a group, those who can assist them with problem solving tasks. This was evident through the actions of the students in this study. Within three months of starting the robotics experience, they could name those who had capabilities in all areas of robotics from programming to building (Chapter 6).

The distribution of mental models is supported by Norman's (1983) "knowledge in the world" and "knowledge in the head" (p. 77) research where he proposed that some knowledge is "left out" of stored mental models. Information is omitted because the model contains procedures or links that will enable such information to be found when required. To illustrate the impact on how much detail is stored in mental models, O'Malley and Draper (1992) used examples of computer menus in their research. They concluded that mental models often contain the procedure to find the information required for task completion or problem solving, but not necessarily the information itself. This fragmentation is a designed act intended to streamline how we use, manipulate, link, and store our mental models so that they are useful when triggered by future problem situations.

The idea of how mental models are distributed amongst individuals is equally interesting because the dialogue that must ensue to solve a problem involves the manipulation of a shared mental model (Anderson et al., 1996; Henderson & Tallman, 2006; Senge, 1992). The manipulation is both external during discussion between those sharing the transitory mental model (Anderson et al., 1996) and internal while the individual works on the model imbuing it with their own experiences, beliefs, and values. Even a shared decision may involve several mental models that, while factoring in the group decision, are interpreted and stored individually by the members of the group and therefore coloured by their individual perceptions, biases, and preferences.

Some social cues, that are employed by people as they collaborate to share mental models, include directing and sharing attention, participating in turn-taking, providing feedback, and guiding exploration of suggestions (Breazeal, 2002). Teachers and students need to recognize that the employment of appropriate social cues and the instantiation of the problem itself require the running of, and linking to, several mental models. This functional multiplicity of mental models has many implications for classroom use of group work and discussion. Multiple socially-constructed environments expose individual students to numerous partners in different contexts and, each of these social constructs, will involve the manipulation of various transitory mental models to find solutions to problems while negotiating working relationships. Consequently, students will be reflecting on how much knowledge they should share out in the world and/or keep in their head in order to develop functional mental models.

If the quality of the dialogue that occurs in group work is dependent on the richness of the mental models (Barker, van Schaik, Hudson, et al., 1998), then this has implications for how groups are formed. Allowing students to select their own groups has merit but their way of communicating their mental models is also an issue. Individuals have a comfort zone and, while being moved from this comfort zone is important to create perturbation (Ritchie et al., 1997) or disequilibrium (Piaget, 1970) that helps induce learning, it is also important that a certain assuredness within a group is maintained for communication of mental models to be effective. We may not “tell all” to those with whom we feel uncomfortable. One of the study participants, Bree, found it very confronting and unproductive to work in mandated groups during the robotics experience. She felt more confident to express her mental models of group interactions in front of a camera in this context than when she was working with other students in a small group or pair (Chapters 8 and 9). Bree’s novice communication mental models had inhibited her development of distributed mental models during the robotic learning experience. This novice versus expert question is another interesting part of the journey of examining mental models.

Novices and Experts and Mental Models

A Question of How We Undertake a Journey of Learning

Bilbo Baggins may have been a novice at undertaking journeys and also recognising the mental models he was using when he was on his journey, but he certainly *used* his mental models to solve novel problem situations. Newton (1996) believed that novices lack the repertoire of cognitive clusters that include the conceptual, procedural, and declarative knowledge necessary to respond to problem situations with broad tactical know-how. Instead they deal with the surface features and details because the mental models they need, in order to be successful in a timely way, are only weakly linked, if in existence at all. In contrast, experts have conceptual, declarative, and procedural knowledge that is hierarchically organised with broader strategies above and narrower ones below enabling them to function more successfully and strategically (Newton, 1996). Sloboda (1996) defined an expert as “someone who can make an appropriate response to a situation that contains a degree of unpredictability” (p. 108). The appropriate response Sloboda (1996) referred to would, therefore, contain conceptual, declarative, and procedural knowledge that experts “deploy simultaneously” to find solutions (Newton, 1996, p. 206).

Experts and novices are also seen to differ in the amount of knowledge they have mastered and how that knowledge is organised (Glaser et al., 1985). The ability to process problems in depth and the appropriateness, or otherwise, of the mental models they have developed are other differentiating factors. Leviton (2003), in his reworking of Morgan, Fischhoff, Bostrom and Atman’s (2001) technique of using mental models to study the communication of risk information in a medical context, found, like Morgan et al., that the “expert’s mental model is highly elaborated” while the “mental model of the layperson (novice) is sketchy and knowledge . . . is quickly exhausted” (p. 529). He also found that the novice’s mental model contained “key mistaken beliefs” (Leviton, 2003, p. 529) that in a medical sense can be potentially dangerous. However, by mapping both the experts’ and novices’ mental models and then making clear comparisons to establish critical points of concern, the medical team were able to develop a shared mental model of practice that avoided life-threatening situations.

The nature of mental models themselves contributes to the development of expert mental models that contain understandings developed from previous experiences in problem-solving (Henderson & Tallman, 2006). These cognitive representations are, therefore, not limited to informal commonsense constructions. Many students, in this study, developed more robust and accurate mental models of robotics as they gained expertise in problem-solving. They moved from a novice action of running single mental models that are retrieved as a “best fit” (Chapter 4) to a more expert action where several mental models were retrieved to be run in parallel or interlinked (Henderson & Tallman, 2006; van der Henst, 1999) to find possible solutions (Chapter 6). A novice’s choice of suitable actions is often from a narrow field rather than the broad strategies used by experts (Newton, 1996) due, in part, to the development of functional mental models over time.

The response time used by novices and experts in problem-solving is also of relevance in classrooms. This construct was studied by Britton and Tesser (1982), who found that knowledgeable or expert users of systems often have significantly longer response times to problem-solving situations due to having less processing capacity available in working memory. The decrease in working memory capacity is because an expert will activate a greater number of mental models for problem-solving than a novice. Novices had greater working memory capacity available to deal with a secondary task because of their lack of mental models available for the primary task. How many times have teachers observed students who have completed a seemingly complex task very quickly when, in fact, they were found to have skimmed over the complexity of the problem to arrive at an inaccurate, incomplete answer? Novices have mental models (Williamson, 1999) that are “fragmented, incomplete, and inaccurate” (p. 21) due, in part, to limited experience. The process of becoming an expert in any domain therefore involves the opportunities to develop a greater number of complete and accurate mental models (Barker, van Schaik, & Hudson, 1998). Such is the goal of education.

Finding a Path through the Trees

Where to From Here?

It is clear from the genealogy of mental model theory (Craik, 1943; Gentner & Stevens, 1983; Norman, 1983) that it was first proposed as an explanation for human interaction with systems. Craik (1943) described mental models as “representations in the mind of real or imaginary situations” (p. 12) and used the theory to explain how individuals explain, understand and solve anticipated events. He saw mental models as allowing users of systems to later explain and make predictions about the actions and reactions of those systems. This became an area of particular relevance to computer designers and engineers who were creating electronic systems that required a user to interact with new languages in order to carry out functions that were previously done manually. Electronics and communication through signals or messages in different languages involved the study of how humans interpreted such systemised exchanges. While how humans interact with their environment may have been of intense interest to ethnographic researchers prior to that point, the elementary need, to ensure that the human-computer interaction is efficient, became a prerequisite for the study of mental models in this area.

It would seem, therefore, that the developments of the technology led the study into the cognitive science that would be necessary for the efficient development of the technology needed. Not every person who used an early model computer had the technological know-how to understand the communication and programming process required for complete proficiency. It is only now, argued Sasse (1997), that how humans represent information mentally and how they use that information to problem solve in the technological world are of interest to researchers in philosophy, cognitive psychology, and cognitive science. Also of interest was Johnson-Laird's (1983) work in text comprehension given that the language used by computer interfaces involves word text and iconic language, and an ever-changing combination of the two. Current language involves audio for some computer programs so there is a rich combination of language types with which users interact. Preece et al. (1994) discussed robotic programming and how language-like procedures may be a preferable way for some people to think and a visual-based program using iconic language may be even simpler for some people due to the more natural way of representing ideas.

The creation and activation of mental models in the act of learning, regardless of the technological system, takes the incomplete and makes it more complete. It takes the internal mental model and exteriorises it for a period of time before returning it to its internal storage facility. It takes webs of related understandings and weaves them into permanent, yet transient short-term memory mental models, that promote stronger links to other related mental models through the very nature of analogy (Gentner, 1998) and structural mapping. The process of thinking creates a cognitive product. But, mental models are more than this. They are there to guide us through the complexities of our environment and to record what happens. We undertake mental modelling in order to solve problems we encounter and, as a result of this process, store the newly created or restructured mental model for future use.

As we continue the journey into mental models and the methods by which they can be studied, it is time to return to our analogy of *The Hobbit* and Bilbo Baggins:

> There were many paths that led up into those mountains, and many passes over them. But most of the paths were cheats and deceptions and led nowhere or to bad ends; and most of the passes were infested by evil things and dreadful dangers. The dwarves and the hobbit, helped by the wise advice of Elrond and the knowledge and memory of Gandalf, took the right road to the right pass. (Tolkien, 1937, p. 53)

A greater understanding of the mental models used in the interactions with phenomena that occur in classrooms can empower teachers and students to tread more confidently on their pathway. This study adds to the increasing body of knowledge on mental models, and the processes by which we can study them, through its focus on five main characters who share their learning journey through new territory.

CHAPTER THREE: *Methodology*

"What has roots as nobody sees,
Is taller than trees,
Up, up it goes,
And yet never grows?" (Tolkien, 1937, p. 71)

Introduction

As Bilbo Baggins traded riddles with Gollum in *The Hobbit*, they were creating puzzles using analogy, metaphor, and memories that relied on word-play in order to provide a challenge. The riddles were, in fact, the remnants of Gollum's mental models of his former life: "Riddles were all he could think of. Asking them, and sometimes guessing them, had been the only game he had ever played with the other funny creatures sitting in their holes in the long, long ago" (Tolkien, 1937, p. 71). Mental model research is often like trying to find an answer to one of Gollum's or Bilbo's riddles. All of the relevant information that is required to find the answer is included in the riddle itself. Yet, it is often in a format that is ambiguous or quasi-analogical. What is required is a methodology that will separate the relevant pieces of information and link them together in meaningful ways so the riddle's answer or, in this study, each participant's mental models are apparent.

Cognitive research seeks to probe beyond the external, somatic displays of participants to observe what takes place in their minds. Qualitative research seeks to provide a "source of well-grounded, rich descriptions and explanations of processes in identifiable local contexts" (Miles & Huberman, 1994, p. 1). The data generated from qualitative methodology have an "undeniability" that Miles and Huberman (1994) believe derive from the "concrete, vivid, meaningful flavour that often proves far more convincing to a reader . . . than pages of summarized numbers" (p. 1). So, qualitative cognitive research, such as that required to unravel the riddles of mental models, comes in many rich, descriptive varieties due to the very nature of what is being studied.

Nature of Mental Models Research

Qualitative research involves both observing and re-telling a story of a journey or a quest such as that in *The Hobbit* (Tolkien, 1937). It involves a binary focus both on the journey markers, through the number of steps or, in this study, the data collection episodes taken to reach a destination, and on the intriguing glimpses of the human experiences afforded along the way. It is the richness of this humanness of a journey, supported by sign-posted structural markers, that makes it interesting and relatable.

Educational research can influence what teachers do if it is plausible, practical, enlightening, and linked to contexts that involve exciting pathways of learning for both teachers and students (McMeniman, Cumming, Wilson, Stevenson, & Sim, 2001). Bilbo's story of learning in *The Hobbit* mattered, because it related an authentic quest for self-enlightenment to social justice for all. Similarly, the story of student learning matters to each classroom teacher in the quest for social justice and equity for all students. Therefore, if students and their learning matter, then so do their stories, their experiences, and their mental models of how they view themselves as learners interacting with each other and with the phenomena in the world created for them.

The discussion that follows excludes any reference to quantitative research because the small-scale nature of this investigation precludes large-scale data collection and analysis within the positivistic paradigm. The study, instead, focuses on what Luke and Hogan (2006) term a "close study of pedagogy, classroom face-to-face teaching, where the work of teaching and learning occurs" (p. 174). Large-scale quantitative methodologies, that often set the scene for political "countability" (Luke & Hogan, 2006, p. 173) do not lend themselves, ideologically or rationally, to such a humanistic study that seeks to reduce any objectivising of data analysis (van Zanten, 2006) in an area of cognitive investigation. This study is positioned in the qualitative research paradigm where the dynamic nature of mental models can be illuminated through a longitudinal approach that incorporates a variety of investigative instruments to determine how teachers and students conceptualise problem solutions by exteriorising their mental models.

Miles and Huberman (1994) proposed three broad approaches to qualitative research that were considered for this study: collaborative social research, interpretivism, and social anthropology. Collaborative social research (Miles & Huberman, 1994), also called participatory action research (Babbie, 2007), occurs where researchers and participants design the interactions together. Data is used progressively both as feedback and planning material for subsequent stages of the study. Such research functions as a "tool for the education and development of consciousness" (Gaventa, 1991, p. 121) and empowers the participants to take action from the information revealed by the research methodology.

Interpretivists, or naturalists (Babbie, 2007), tend to capture the essence of data from interviews and observations without reliance on coding and other reduction techniques. The data collected are often reported without reduction because interpretivists, like phenomenologists (Schutz, 1967, 1970), are sceptical about condensing or reducing field material that is gathered often over long periods of time. While Schutz's (1967, 1970) research was predominantly in the area of economics, he focussed on commonsense knowledge (Forstater, 2001) and attempted to incorporate complex social commentary with rigorous scientific interpretation. This melding of foci acknowledged that research participants are best studied within a context. Interpretivists, such as Dilthey (1911/1977) and ethnographers (e.g., Whyte, 1943; Snow & Anderson, 1987; Snow, Morrill & Anderson, 2003) believed that researchers and participants are not detached and the data collected almost becomes a combination of conceptual interpretations from the points of view of both parties.

The case study involves an in-depth investigation into a specific case, whether a school, a class, or an individual teacher or student. While the approach used for this project replicated methodologies consistent with those that would be instantiated in a case study — such as interviews, observations, questionnaires, and journals — the multi-layered nature of the involvement of the variety of participants precluded the label, case study, being completely applicable. More importantly, the artificiality, that is often associated with the separation of case study participants to provide a homogenic group (Burns, 2000), was not appropriate to the longitudinal nature of this study and its context within the school community.

Social anthropology also involves close contact with the target community, or participant group, and includes the ethnographic features of naturalism (Babbie, 2007; Miles & Huberman, 1994). Its focus, however, is more on the study participants' interpretations and includes a study of functionality and communication through relationships, language, artefacts, and rituals (Miles & Huberman, 1994). There is a common use of electronic media, such as video and audio-tape recorders, to collect the large amount of data that is more structured in format but also readily available to code and categorize for analysis (Miles & Huberman, 1994). These elements and formats are found in various qualitative paradigms. Elements of the social anthropologist perspective can be seen in this study in terms of the extended contact with the participants, the focus on their perspectives or mental models, and the use of various sources of data that have been coded, categorised, and subsequently analysed. Although these elements are visible in this study, it was not a social anthropological project.

Akin to the social anthropologist perspective, this study utilised data reduction processes such as "selecting, focusing, simplifying, abstracting, and transforming"

(Miles & Huberman, 1994, p. 10), but the richness has not been lost from the "thick descriptions that are vivid, nested in a real context, and have a ring of truth" (Miles & Huberman, 1994, p. 10). The richness and vividness are due, in part, to the very nature of mental models. They are idiosyncratic (Norman, 1983), personal and reflective of teacher and student journeys. While themes may be evident in the mental models expressed by the participants, their individual essence has not been lost by reduction.

This empirical qualitative study was centred within information processing theory and linked with the introspection mediating process tracing paradigm. Information processing presents a significant conceptual framework (Kail & Bisanz, 1992; Lohman, 1989, 2000) that provides the model to "look inside the minds of learners to explore what happens when learning occurs" (McInerney & McInerney, 2006, p. 96). Early explanations of the theory involved a mechanistic focus on inputs and outputs such as those found in behaviourism (Watson, 1913, 1916, 1930; Thorndike, 1913, 1931). Later constructs of the theory focussed on learner centredness and their selection, organisation, and integration of new experiences with existing knowledge or the processes that are used in metacognitive activity, that is, the meta-mental processes (Mayer, 1996).

The analogy of the human mind to a digital computer (Flavell, 1985), through its manipulation of incoming data to complete a task or solve a problem, is linked to the activation of various processes that may include encoding, recoding and/or decoding, comparing, and assimilating (McInerney & McInerney, 2006). This activity involves the activation of three types of memory: sensory, short-term (working), and long-term (Atkinson & Shiffrin, 1968) through which input is channelled, negotiated, and acted upon in some way to produce an outcome. This outcome could be described as a "product" of the learning process with a focus on what input will produce what output.

Mental model theory, while opening its individual idiosyncratic "process/product" bimodality as a topic (Chapter 2), cannot be fully explored without the addition of the mediating process tracing paradigm. This paradigm "focuses attention on the importance of ascertaining ... the mental models of participants when carrying out a task" (Henderson & Tallman, 2006, p. 60). The mediating process tracing paradigm makes no causal assumptions about the links between student outcomes or actions to particular inputs or stimuli (Marland, Patching & Putt, 1992) and is, therefore, particularly relevant to a study, such as this, that sought the determination of espoused, in-action, and reflective mental models (Henderson & Tallman, 2006).

Research Aim and Questions

Research Aim

The research aim was to examine how a teacher's and students' mental models can inform teaching and learning and how they may contribute to the development of authentic assessment practices in a technology-based learning experience.

Research Questions

1. What are the mental models of primary school students and their teacher before, during, and immediately after technology-based learning experiences?
2. What are a teacher's and four of her students' espoused, in-action, and reflective mental models of teaching, learning, and assessment?
3. In what ways have these mental models (identified in 1 and 2)
    a. matched, mismatched, and/or changed, and
    b. the effect, if any, on teaching, learning, and assessment?
4. In what ways have the mental models managed the participants or been managed by the participants throughout their engagement in the teaching, learning, and assessment experiences, longitudinally?

The research aim and questions were designed to enable multiple journeys to be mapped. These Bilbo-like journeys, with distinct signposts planned along the way, proved its robustness as it allowed adaptations of methodology to occur that would enrich, not only the collection of data for this study, but also the protocols for such data collection instruments in cognitive science, generally, and mental models specifically.

Context of the Study

The school involved in the project opened in 1960 and is in an urban area in regional Queensland, Australia. The campus had 550 students from Preschool (four years of age) to Year Seven (twelve years of age) in the year 2005. There were twenty-three classroom teachers; seven support teachers, in areas of library, physical education, music, special needs; and eight teacher aides who worked with children and teachers in classrooms. Behaviour management had been a strong focus of the school and the predominant role of the deputy principal was to support staff and parents with establishing and maintaining appropriate student behaviour so that a productive learning environment was created and maintained across the school.

The *Queensland Technology Years 1 to 10 Syllabus* was released in 2003 and included Robotics as an optional module of study in the curriculum. Robotics was newly introduced in the project school in February 2005 as part of the Technology Syllabus for Year Six students. This introduction coincided with the commencement of this study. The teacher participant, Pamela, established a small robotics laboratory (see Figure 2.1) with six stand-alone computer terminals and three robotics kits in February 2005.

Figure 3.1 Robotics laboratory showing three of six stand-alone computers (left, centre and right)

Robotics Laboratory

The small room used for the robotics laboratory had been designated as a withdrawal room prior to its make-over. It was located between two double-teaching spaces, one of which was used by Pamela and another teacher and class, and the student participants who participated in the study. The laboratory could be accessed through an external doorway from a shared foyer and internal doorways from each of the two double-teaching spaces. Once the room had been emptied of existing equipment and furnished for the robotics laboratory, it contained several non-computer specific desks, tables, and benches (Figure 3.1) and six stand-alone computers that had been “salvaged” from classrooms around the school.

In other words, the computers that Pamela appropriated were “aging” and had a variety of configurations. This meant that the physical locations of Universal Serial Bus (USB) ports varied and students had to become familiar with these differences as they were not allocated to the same computers for the robotics lessons. Two of the computers struggled to deal with the Robolab™ software and crashed frequently throughout the sessions. This caused student consternation and some fluency problems with the data collection in early stimulated recall research sessions. Although annoying, these occurrences were part of the “reality” of the classroom and, therefore, captured in this study.

At the start of the program, there were three kits containing the Lego™ Dacta equipment and Robolab™ software for use among the entire group of 58 students who would be learning with the program. This limitation of equipment posed some organisational considerations for Pamela but there was sufficient equipment to enable all students to work each week for at least forty minutes on the program. Even so, the class and equipment arrangements required to deliver the robotics activity challenged Pamela and her teaching partner, who did not teach robotics. The challenge was to arrange learning experiences, for an entire year’s program, that were both flexible and learner-centred given the problem-solving nature of the robotics program. The school did not officially support the program through purchase of kits or provision of computer equipment or furniture. All monies spent to establish the learning experiences were from donations within the school. This involved fundraising discos and free-dress days organised by the senior students and personal donations of money by some teachers.

The overall situation made the problems associated with delivering the program difficult but it was not allowed to be insurmountable. The lack of infrastructure support from the school leadership also signifies the talent, dedication, and perseverance of Pamela, the teacher in the project, and the interest by committed students to ensure that materials were purchased for the robotics laboratory to be established.

Robotics

Robotics is a component of the Queensland Technology Syllabus (2003). It provides a rich, multi-disciplinary environment in which to engage middle years students in designing, building, programming, and activating robots to complete set tasks. The syllabus document provides guidance on planning and assessment for design and technology activities and a specific module for robotics without mandating particular content. The syllabus also promoted cross-curricula priorities and the engagement of students in life-long learning experiences, including reflective practice and responsive creativity. It was supported by a bank of discretionary thematic modules that offer teachers well theorised, planned, and resourced discovery-based learning experiences.

"Introducing Robotics" (Queensland Studies Authority, 2003) is one of the supplementary, discretionary modules designed to engage students in learning outcomes from Level 6 (Middle Years - Lower Secondary). It provides teachers with sequential activities for students to build and program robotic devices using Lego™ Dacta equipment and Robolab™ software. The student activities are organised into introductory, developmental, and culminating phases as shown in Table 3.1.

Table 3.1: Synopsis of Activities from "Introducing Robotics" (QSA, 2003, p. 1).

Introductory	Developmental	Culminating
Formulate plans for gathering information and acquiring relevant skills.	Analyse the design challenge and prepare project proposals and design briefs.	Trial and refine robotic devices.
Research and discuss robotics.	Devise project management plans.	Evaluate robotic devices.
Follow instructions to build robots and use sample programs.	Prepare product specifications.	Evaluate personal and team performances.
	Construct/program a robot.	

Examples of assessment strategies are included in the module and provide guidance to teachers as to how they may assess the demonstration of outcomes. The module reflects the pedagogical characteristics of the syllabus by suggesting negotiated assessment practices that include opportunities to reflect with the students on the evidence collected. The predominant source of evidence is the student technology project folio, templates for which are provided in the module. Templates for design proposals and briefs, product specification sheets, and project management plans are also provided. In summary, the module provides useful guidance for teachers to implement and assess a robotics program using constructivist pedagogy. While Pamela did not use the template included in the module to structure her program, she did use it as a reference to create a simplified journey of learning for the students that also incorporated language components (Data Collection Tools, Journal Section, this Chapter).

Participants

Teacher Participant

Pamela was an enthusiastic participant in the study. She valued research, especially that involving her own teaching. When the project began, Pamela had been a practising middle-years teacher for eight years. In 2005 she worked with a teaching partner in an open-plan teaching space that contained 58 students and six internet-linked computers. She acted as a peer mentor to other teachers in science and computer studies and worked passionately to ensure that all students engaged with each other and the information communication technologies in a supportive and challenging environment.

> I think that the students of today are able to work with a lot of different information on different levels and combine that information. They also like to have hands-on, where they're actually doing something. It's [robotics has] got a real-world application and so, to make those connections with the wider world, they need to be able to see how the things they're doing in the classroom actually link further out. (Pamela, Pre-Experience Interview, 26 February, 2005)

Thus, her philosophy of teaching embraced social constructivism that was apparent from her pedagogical practices.

Pamela had undertaken some professional development in robotics in the two years leading up to the project implementation, and decided to commence a program that would reignite enthusiasm for learning in the students in her class (Pamela, Pre-Experience Interview, 26 February, 2005). Many of the students were starting to disengage from active participation in the curriculum due to escalating behavioural and learning problems and Pamela saw the use of a learner-centred activity, such as robotics, as one means of re-engaging students (Pamela, Pre-Experience Interview, 26 February, 2005). She succeeded. Students took pride in their robotics endeavours and invested ownership in the program and developed custodianship over the equipment.

Student Participants

All 25 student participants were in Year Six at the school, that meant they had had at least five years of formal schooling experience that they were bringing to the project. They were 10 years of age at the commencement of the project in March 2005 and would turn 11 that year. By the end of the project, in October 2006, the students were 12 years old. As per school policy, the students were tested biannually to establish their reading ages using Rigby PM Coleccion Benchmark Kit (Rigby, 2004). The 2005 scores for the year-level cohort, to which the participant students belonged, varied significantly from ages 7.5 years to beyond 13 years. The majority of students fell in the nine to ten years reading age band. Learning support was provided through daily in-class remediation and assistance and through withdrawal to special needs' classes twice each week for those children who required extra tuition. None of the anonymously selected participants required withdrawal to special needs' classes.

Consideration of general academic ability was a minor factor considered by Pamela when the 58 students were arranged into pairs or groups of three for the robotics experience. She selected the groups by asking them to write on a handout: (a) who they would like to work with, (b) who would they take away with them for a week, and (c) who they would have assist them if they were doing an exam. While students are often asked with whom they would like to work, Pamela included the additional questions, (b) and (c), in order to focus the students on the reasons why we might choose particular people with whom to work. Question (b) encouraged the students to think of the efficacy of a long-term relationship with their partner. Question (c) aimed to focus part of their decision making on the competence that their prospective partner might demonstrate. Once those three pieces of information were collected, she would determine the groups of two or three that, for most, continued for the robotics experience.

Ethics

Prior to the commencement of the project, all students in the classes taught by Pamela and her teaching partner were given a letter explaining the project and a detachable consent form to secure the parental or guardian consent for participation in the project (Appendix A). Of a possible 58 students, 25 returned informed consent forms and the permission to use photographs and/or videos of the students for conference purposes. The entire cohort of students, including these 25 participants, was divided into four groups so as to enable concurrent activities to be timetabled. Students were then partnered for the activities in accordance with their responses provided to Pamela's group handout forms.

The returned student consent forms were placed in two piles separated by gender. While there were no gender-specific qualifications in the project, the students' perception of gender equity informed this approach to student selection. From each face-down pile of consent forms, a volunteer adult not associated with the class or the project selected two forms from each pile thereby providing the four (4) student participants and one (1) substitute who would engage in the more in-depth data collection (Data Collection Tools Section). The four selected students were paired by the teacher: the two boys Sam and Jim and the two girls Ellen and Jayne. Unfortunately, one of the male participants, Jim, left the school shortly before the end of the first year and he was replaced by the female substitute, Bree, who had been involved with the more in-depth data collection methods from the commencement of the project, in the event of such a contingency (Table 3.3 this chapter). This meant that, for most of the project, the participants were three girls and one boy. Bree was not paired with Sam, after Jim left the school, as she had already been working, for some time, with her own partner. There were no gender qualifications in the design of the project so this did not influence the analysis of the data or subsequent reports of the findings. Two of the four participating students were in Pamela's class group and two were in the other participating class and, due to the flexibility of timetabled activities, their attendance in the data collection sessions was able to be accommodated.

Four other students, randomly selected from another Year Six class not associated with the project, were asked to participate in one of the data collection episodes. They were given a letter explaining their participation in the project and a detachable consent form to secure the parental or guardian consent (Appendix B). Pamela also signed a consent form for the project (Appendix C).

All returned and signed forms were stored in a locked filing cabinet in a locked room in the residence of the researcher. All data collection instruments were labelled with pseudonyms selected by the individual participants and no actual names were recorded on any hard or electronic copies. A record of the pseudonyms and their owners was securely stored in the aforementioned locked filing cabinet by the researcher. The electronic record of data was filed under a different password to its subsequent analysis that was stored on an individual computer of the researcher. All of the data and analysis is backed up to two different USB sticks that are also password protected using different passwords and locked in a separate filing cabinet, with a different key for security, in the residence of the researcher.

Data Collection

Timeline of Collection

Time is a vital dimension in designing and implementing an applied research project, especially one that is following a real-time learning project in a school. In this study, the effective collection of data relied on many difficult variables attributable to the school context, including: timely access to students during in-class activities, continuation of instruction regardless of computer failure, and the departure of one of the in-depth study participants.

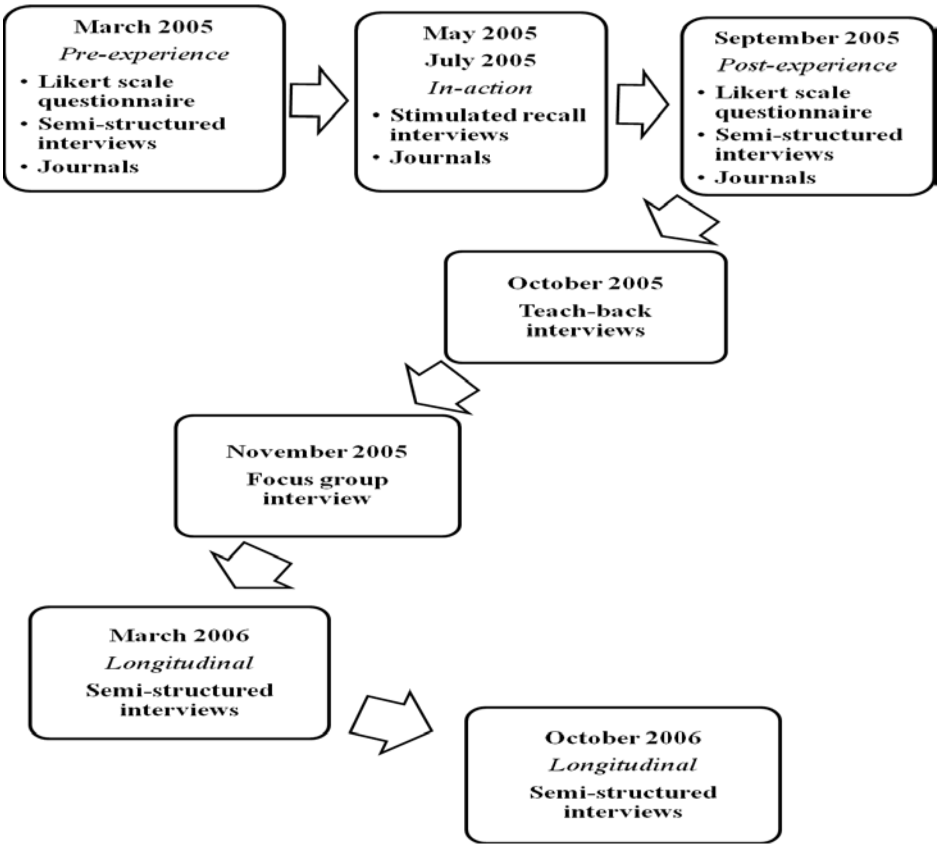

Figure 3.2. Data collection points and instruments used with participants in the study

Because the project was a longitudinal study over 20 months, it was vital that as many of these hard-to-control variables be “controlled” through ensuring the variety of methods for data collection “fitted in” and was coordinated with the teacher participant’s classroom organisation and curriculum implementation through forward planning. “What-if” scenarios were discussed with the teacher and alternative strategies and a time-line, depicted in Figure 3.2, were created to ensure that data could be collected at the appropriate time frames throughout the project. An example of the enactment of the what-if scenario occurred when the stimulated recall episodes, conducted three months into the project, failed to elicit sufficient data to enable meaningful analysis. The second round of stimulated recall interviews, including a change of protocol, was able to be timetabled into the teaching/learning schedule due to the discussions held earlier about such eventualities and the rigorous planning undertaken with the teacher, Pamela.

Data were collected from the teacher, Pamela, and the students over a 20-month period as illustrated in Table 3.2 (next page). It provides more detailed information than the timeline of data collection (Figure 3.2, previous page). As mentioned earlier, five students were anonymously drawn from the total group of 25 participants and, due to attrition, four of these students participated in the interviews, teach-back episodes, and focus groups. These four students (Table 3.3, page 66) and Pamela also participated in the longitudinal aspect of the project that involved a semi-structured interview in March 2006, six months after their post-experience interviews in September 2005. A final paired interview was conducted a further seven months after the March 2006 interview with two of the students, Ellen and Bree, and another semi-structured interview was held with Pamela at this time in October 2006 (Figure 3.2, previous page). An overview of the individual student participants has been included in Table 3.3 (page 66) to illustrate the considerations that needed to be made for data collection throughout the study.

Table 3.2: Detail of Data Collection Instruments Used in the Study

Instrument	*Likert Scale Questionnaire*	*Semi-Structured Interviews*	*Journals*	*Stimulated Recall Interviews (SR)*	*Teach-Back Episodes*	*Focus Group Interview*	*Longitudinal Semi-Structured Interviews*	*Longitudinal Semi-Structured Paired Interview*
Conducted by	Researcher	Researcher	Teacher	Researcher	Researcher	Researcher	Researcher	Researcher
Collection Point	Pre: 10/03/05 Post: 08/09/05	a. Pre: 1-13/03/05 b. Post: 5 & 6/10/05 c. 26/11/05	March–November 2005	SR1 5 & 6/05/05 SR2 14 &15/07/05	03/10/05	a. 14/11/05 b. 15/11/05	16-18/03/06	30/10/06
Participants✱	Teacher Students N=24	a-c: Teacher a-b: Students N=4	a. Teacher b. Students N=24	Teacher Students N=3	Students N=8	Students N=4	Teacher Students N=4	Teacher Students N=2
Duration	30min	30min	a. intervallic b. during robotics lessons	Lesson=30min Interview =30min	Lesson=20min Interview =10min	a. assessment session =2 x 30min b. Interview =30min	30min	30min
Purpose	Espoused and reflective mental models for matches, mismatches, and changes		a. Matches, b. Mismatches, c. Student progress	In action mental models (see Ch 5)	Mental models of teaching and learning (see Ch 7)	Mental models of learning and assessment (see Ch 7)	Stability or otherwise of mental models of learning and assessment over time	
Media	Paper	Audio recorder	Paper	Video camera; audio recorder	Video camera; audio recorder	Video camera for both sessions	Audio recorder	Audio recorder
Reference	Appendices E-H	Appendices I-L	Ch 3, Table 3.8	Ch 5	Appendix V	Appendix W	Appendices O and P	Appendices Q and R

✱ To be read in conjunction with the following table, Table 3.3.

Ch = Chapter

Table 3.3: Student Participants' Involvement from March 2005 to October 2006

Student	Espoused Pre SS* Interview	In-Action SR1#	In-Action SR2#	Reflective Post SS* Interview	Teach Back	Focus Group	Long'al SS* Interview	Long'al Paired Interview
Bree	Bree			Bree	Bree	Bree	Bree	Bree
Ellen	Ellen	Ellen	Ellen	Ellen	Ellen	Ellen	Ellen	Ellen
Jayne	Jayne	Jayne	Jayne	Jayne	Jayne	Jayne	Jayne	
~~Jim~~	~~Jim~~	~~Jim~~	~~Jim~~					
Sam	Sam	Sam	Sam	Sam	Sam	Sam	Sam	
Axel					Axel			
Belinda					Belinda			
Eliza					Eliza			
Mary					Mary			

SS* = semi-structured
SR1#, SR2# = stimulated recall
Long'al = Longitudinal
Notes:

a) Jim participated in three data collection events but his data was excluded when he left the school prior to the reflective post-experience, semi-structured interviews in September 2005.
b) Bree did not participate in either of the stimulated recall data collection episodes in May and July 2005.
c) Jayne and Sam had both left the school and were unavailable for the second longitudinal interview in October 2006.
d) Axel, Belinda, Eliza, and Mary were from a different class in the same Year Level that did not participate in the robotics activities.

Student attrition resulted in the substitute participant, Bree, engaging in all data collection episodes after the stimulated recall investigations. Her non-participation in the stimulated recall interview, due to school absence, was unavoidable. Table 3.3 also indicates Jayne and Sam's non-participation in the second longitudinal interviews at the end of the study that occurred after they had left the school. The four students, Axel, Belinda, Eliza, and Mary, participated only in the teach-back data collection episodes and took the role of novice pupils (Chapter 7).

This longitudinal methodology was planned prior to commencement of the project. Nevertheless, some instruments were adapted, including the stimulated recall interviews in July 2005 and the longitudinal interview in October 2006. The implemented protocols were inadequate in providing useful data in the stimulated recall interviews so an adaptation was instantiated (Chapter 5). This was noted in methodology journal (Appendix S), "What of 'don't knows'? Lit [literature] suggest something? Could adapt meth [methodology] next time to enable students to explain <u>what</u> they were <u>doing</u> – new way to look at SR [Stimulated Recall]" (Researcher's Journal, 8 May 2005). Two students (Bree & Ellen, Table 3.3) were interviewed simultaneously in October 2006 to investigate the distribution of mental models

(Chapter 9). Also, two additional data instruments, the assessment episode and focus group interview in November 2005, ensured a more robust picture of the participants' shared mental models. The chapter now explicates the data collection instruments outlined in Figure 3.2 and detailed in Table 3.2 that were used in the study.

Tools of Collection

Likert Scale Questionnaire

Likert scales created by Rensis Likert (1932) have the value of "unambiguous ordinality" (Babbie, 2007, p. 170) enabling the researcher to gauge the relative strength of the participants' agreement to the various statements. The scale is also useful in determining the "relative intensity of different items" (Babbie, 2007, p. 170) where scores are assigned to selected indicators for item analysis. The purpose of the Likert Scale was to develop the levels of measurement through standardising the response categories, thereby enabling determination of the relative intensity of items included on the questionnaire (Burns, 2000). Questionnaires were conducted at two collection points in the study (Table 3.2, this chapter).

A five point scale was used for the questionnaires in this study. The scale moved from left to right with "strongly agree" being the first left hand response and "strongly disagree" being on the extreme right of the scale. The reason that the questionnaires (a) had a five point scale and (b) followed this left to right progression of agreement to disagreement was because this replicated previous experiences the students had had with similar opinion-style school questionnaires. While there is an assumption that most participants in a Likert Scale questionnaire will understand that the "strongly agree" choice will show a more favourable attitude to a statement than "agree" (Burns, 2000), this was not taken for granted with children aged 10 years. Therefore, the student participants in this study were given an example to illustrate the judgment. The example focussed on an unrelated issue: "I enjoy playing handball at lunchtime." The selection of "strongly disagree" was discussed in terms of a negative response to the statement in comparison to "disagree". The selection of "not sure" was also discussed to ensure that participants understood how the selection of that point on the scale would represent how they felt toward the statement.

An attitudinal synopsis was prepared in conjunction with the teacher's and students' sets of Likert Scale questionnaires to ensure that the categories of questions matched the categories used in other data collection tools. The categories are outlined in Table 3.4 below. These reflect the general mental models types that were used for the “Pre- and Post-Experience Likert Scale Questionnaires: Students”.

Table 3.4: Pre- and Post-Experience Likert Scale Questionnaire: Students (2005)

Mental model	Pre-experience item No.	Post-experience item No.
Declarative knowledge	3, 8	3, 8
Procedural knowledge	8, 9, 15, 25, 27, 30	8, 9, 15, 25, 27, 30, *35, 37, 38*
Conceptual knowledge	2, 4, 6, 10, 11, 14, 25, 27, 28, 29, 30	2, 4, 6, 10, 11, 14, 25, 27, 28, 29, 30, *36*, *39*
Predictions of success	1, 2, 4, 5, 7, 11, 13, 16	1, 2, 4, 5, 7, 11, 13, 16, *33, 35, 36, 37, 40*
Social constructivism	12, 13, 26, 31, 32	12, 13, 26, 31, 32, *40*

Note: The 10 additional Post-experience Likert Scale questionnaire numbers are indicated in italics. See Appendices E and G for pre- and post-experience questionnaire items, respectively.

All of the questions from the Pre-Experience Likert Scale Questionnaire were repeated in the Post-Experience questionnaire, albeit with a change of tense for some in order to reflect the students’ journey with robotics. Questions 33 to 40 were added to the Post-Experience Likert Scale Questionnaire to provide students with the opportunity to reflect on their actual experiences, such as working with robotics and with others.

Interviews

A variety of interview formats were used to determine the mental models held by the participants at particular intervals throughout the study. While conducting interviews enables the researcher to have the opportunity to establish rapport with the participants, they also provide flexibility for repetition of probes (Burns, 2000). Elasticity of interactions is valuable, especially when working with young participants where the opportunity to extrapolate semantics is frequently required. Interviews also enable the investigative items to be sequenced as this progression supports homogeneity of interview across several participants.

Semi-structured interviews..

Interviewing is of a “continuous nature” because “questioning is re-designed throughout the project” (Rubin & Rubin, 1995, p. 43). The interaction between the researcher and the participant is fluid and autonomous, much like the mental models of the participants. Although every interview is different, each is centred on set questions, hence, the semi-structured nature of these interviews. Kvale (1996) offers the "traveller" analogy for a researcher or interviewer as she "explores the many domains of the country, as unknown territory or with maps, roaming freely around the territory" (p. 3). Such was the case with the interviews in this study. The personal reflections of each participant had the potential to lead the interviewer down relevant pathways in an attempt to discover the nature of the mental models being revealed.

Caution is needed when interviewing younger children who are conditioned to please adults, particularly teachers, with their responses (Burns, 2000; Schunk & Pajares, 2004). The semi-structured nature of the interviews also allows the questions to be shaped as the interview proceeds, thus requiring an interviewer "to be able to listen, think, and talk almost at the same time" (Babbie, 2007, p. 306) in order to interpret responses and frame subsequent questions. Important guidance comes from experienced interviewers who can adopt the role of the "socially acceptable incompetent" (Lofland & Lofland, 1995, p. 56). In this case, the interviewer appears to need assistance to understand even the most basic concepts being discussed, or so it might appear to an interviewee who has been asked to explain the same issue several times from different perspectives. This occurred in the semi-structured interviews in this study.

Pre- and post-experience semi-structured interviews were conducted with the participants (Table 3.2). Each student spent 30 minutes on campus in a large open room with the interviewer. A non-participating teacher was at another end of the room facing the backs of the interviewee students but not within hearing distance. This adhered to Education Queensland protocols that require more than one teacher in a classroom with an individual student. The students were advised not to discuss their interviews with any other students thus ensuring confidentiality and the unlikelihood of contamination of data. On checking, the students affirmed with pride that they had not talked about their experiences. Each interview was audio-taped.

The students responded to questions that were arranged in categories similar to those used in the Likert Scale Questionnaire (Table 3.4). Each new category commenced with an introduction question, "Tell me what you know about . . ." to establish the participant's mental models of the area before more specific questions were posed. Most areas had four or five specific questions planned in order to provide a platform from which to compare the participants' responses during the analysis stage. Participants were encouraged to extrapolate responses and threads of interest were followed to ensure they had the opportunity to fully express or explain their views. The broad categories of mental models covered in the students' Pre- and Post-Experience interviews are shown in Table 3.5.

Table 3.5: Themes of Mental Models Addressed with Sample Questions in Semi-Structured Interviews with the Students

Interview	Mental model	Sample Questions
Pre- and Post-Experience Semi-Structured	Declarative k	What materials might you use to make a robot?
	Procedural k	How do you make a robot?
	Conceptual k	What is a robot?
	Predictions of success	Could you make a robot?
	Social construction	Do you like working in groups? Why/why not?
		Extra questions added:
Post-Experience Semi-Structured	Procedural k	How did you solve the problems you encountered?
	Conceptual k	What did you learn?
	Predictions of success	Do you see yourself continuing with robotics? Why/why not?
	Social construction	How did you find working in groups? Why?

Note: k = knowledge; see Appendices I and K for full details of the semi-structured interviews.

The teacher participant's semi-structured interviews were also conducted in March (pre-experience) and September (post-experience) in a neutral location after school had finished. An off-campus environment was negotiated with the teacher to ensure that the time she scheduled for the interviews had as little impact on her professional or family life as possible. This location also ensured that interruptions or distractions would not impact negatively on the flow of the interview. The broad categories of mental models addressed in these interviews are shown in Table 3.6 below, and have some relationship to those used for the students. Crucially, the question categories were designed to enable the teacher to express her mental models on both teacher and student interactions and processes as well as ensuring that replicable categories would maximise the validity and credibility of the data.

Table 3.6: Themes of Mental Models Addressed with Sample Questions in Semi-Structured Interviews with the Teacher

Interview	Mental model	Sample Questions
Pre- and Post-Experience Semi-Structured	Pedagogy	How will/did you structure the class for the robotics lessons?
	Cognitive goals	How will/was making a robot different from doing other class projects?
	Cognitive processes	What planning outlines or design brief will/did the students use to plan and record their learning experiences?
	Assumptions	Had the students worked with robots before? [pre]
	Predictions of success	How successful were your planned learning experiences? [post]
	Social construction	Will/did the students like working in groups?
	Assessment	How will/did you report on learning to interested parties?
Post-Experience Semi-Structured		*Extra questions added:*
	Student enjoyment	What did they enjoy most / least about their robotic experience? Why?
	Student opportunities	What else would you have liked the students to have done with robotics but did not have the opportunity?
	Students' strengths and weaknesses	What did they find the easiest / hardest part of working with robots?
	Problem-solving	How did they solve the problems they encountered?
	Student learning	What did they learn?
	Project continuation	Do you see yourself continuing with robotics? Why/why not?

Note: See Appendices J and L for full details of the semi-structured interviews.

The extra questions added to all of the post-experience interviews tapped how other relevant themes had become significant during intervening period. The decision to extend the themes exemplifies the strengths of qualitative research and its organic nature. Data collected over a "sustained period" (Miles & Huberman, 1994, p. 10) makes it possible to be flexible with the methods of collection and allow variation within those methods that reflect the social world being studied.

Longitudinal interviews.

The longitudinal aspect of this study was integral because of its contribution to new understandings of mental models. The longitudinal study, as part of developmental research (Henderson & Tallman, 2006), aimed to account for changes occurring in certain relationships over time (Cohen et al., 1995) or, in this case, whether or not the mental models of the participants remained stable, were abandoned, or were reworked over time. The four student interviewees and the teacher participant were involved in the longitudinal semi-structured interviews in March 2006, six months after the post-experience semi-structured interviews had been conducted. None of the students were involved in a current robotics programme, but the teacher, Pamela, was soon to commence a robotics activity with her new cohort of students. As previously stated, the ethical conditions for the conduct of these interviews were replicated to ensure adherence to protocols.

The specific aspects of stability, abandonment, or restructuring of mental models that were to be addressed in the longitudinal interviews of students (Appendix O) were based on the same categories that were used in the post-experience interviews (Table 3.6). Some additional questions were included at the end of the interviews, such as: “Do different types of assessment suit different students?” and “What is fun in learning?”. These investigated various learning and assessment issues that had been raised by the students in the focus group interview in November 2005. The teacher’s interview (Appendix P) followed a similar format to that undertaken in the post-experience semi-structured interview.

Six months later, in October 2006, a semi-structured interview was held with two of the student participants, Ellen and Bree, who were still at the school. Pamela, who continued to teach at the school, was also interviewed at this time. Using only two students at this time was an example of “sample mortality” (Cohen et al., 1995, p. 71) as interviews for the other two students, Sam and Jayne, could not be organised due to family commitments. Ellen and Bree were interviewed together in a smaller version of the focus group interview conducted one year earlier (Table 3.2, this chapter). By pairing the students, it was hoped that, given the six months gap, their mental models would be distributed through the development of a discussion thereby yielding a greater range and depth of responses (Watts & Ebbutt, 1987). While the categories included in the interview questions remained the same as the previous interviews, there was less emphasis on specific questions related to robotics and more general questions relating to teaching, learning, and assessment. Questions were designed to meet Research Objective 4 entailing the determination of the stability or stagnation of the participants’ mental models.

By the time the longitudinal interviews were held in October 2006, Pamela had implemented a robotics programme with a new cohort of students and had a great deal of comparative information to offer, providing a rich source of mental models on robotics, learning, assessment, social constructivism, and pedagogy. The questions in this interview (Appendix R) included the same categories as in the previous interviews with opportunities to reflect on the success or otherwise of the first robotics programme in 2005. Questions also probed the stability or stagnation of Pamela's mental models and how they were managed to guide the organisational structure and assessment strategies for the current project.

Stimulated recall interviews.

Stimulated recall is a research technique associated with introspective information processing where recall of thoughts can be enhanced by the use of prompts, such as replaying a video taken of the lesson or interview (Ericsson & Simon, 1984, 1987; Gass & Mackey, 2000; Henderson & Tallman, 2006; Pausawasdi, 2002). It was first used by Bloom (1954) as a method to study the recall reliability of students after a classroom event. It has been used effectively in education studies that involve such diverse contexts as children's use of argument (Benoit, 1995), students' learning perspectives (Erickson & Mohatt, 1977), social issues in writing (DiPardo, 1994), sporting participation (Lyle, 2003), pre-schoolers playing (Theobald, 2008), and a comprehensive view of teachers' Information Communication Technology (ICT) learning tools (Beers, Boshuizen, Kirschner, Gijselaers & Westendorp, 2008). The use of the methodology has also included research into mental models where in-action mental models and decision-making strategies held by students and teachers during instructional activities were studied (Gass & Mackey, 2000; Hannigan & Reinitz, 2001; Henderson & Tallman, 2006; Meade & McMeniman, 1992). Stimulated recall is often used with other data collection methods, as in this study, to triangulate data for validity and authenticity with a particular aim to reveal cognitive processes that are not usually evident by other methods, including direct observation (Ericsson & Simon, 1984; Gass & Mackey, 2000).

Bloom (1954) proposed that the strength of the stimulated recall procedure is enhanced by providing a number of cues from the original situation, such as a video or audio recording, to "reactivate or refresh recollection of cognitive processes so that they can be accurately recalled and verbalised" (Gass & Mackey, 2000, p. 53).

The information being accessed by stimulated recall is the conscious thoughts of the participants during a previous activity and the use of the video (Pausawasdi, 2002) provides a visual and aural stimulus because it is an accurate documentation of what occurred during that activity.

The validity and reliability of responses given in this study’s stimulated recall interviews were maximised by adhering to strict protocols. These include the immediacy of the interview after the event, unambiguous instructions for pausing of the video replay, clear question prompts, and non-directive questioning.

The immediacy of interview after the recorded episode improves both recall accuracy (Bloom, 1954; Reder, 1982) and the number of recalled thoughts (Gardiner & Parkin, 1990). Bloom (1954) ascertained a 95 percent accuracy of recall if the interview was conducted within 48 hours of the event but this substantial level of recollection precision fell to 65 percent if the interview was two weeks later. Gardiner and Parkin (1990) confirmed Bloom’s findings and also discovered the greater likelihood of participants providing explanatory evidence rather than accurate recall the longer the gap between the event and the interview.

The initiation of pausing the video, that can be instigated by the researcher or the participant, is another important consideration. The video can be paused at any time thereby helping to ensure that the full spectrum of recalled thoughts will be revealed, either through question prompts by the researcher or specific recalled thoughts by the participant. The instructions, that explain the initiation of pauses and given to participants prior to the video replay, are important as it is here that trust and understanding are being established. Students are invited to initiate a pause on the video at places where specific thoughts are recalled. When the researcher is waiting for the participant to pause the video replay, Ericsson and Simon (1984, 1987) proposed that any reminders provided for the participant to continue verbalisation at that time should be kept to a minimum. Minimal interference in the process of remembering allows participants to concentrate of what they are viewing while attempting to create the required links to long-term memory.

Question prompts used by the researcher are a vital contributor to rigour, validity, and reliability. Questions such as, “What were you thinking here/at this point/right then?” (Gass & Mackey, 2000, p.154), should be used to prompt participant recall of their mental content or processes (Johnson, 1964; Webb, 1975) at particular times of interest. When such a prompt is given, a response of “don’t remember/know" or "can't remember" may be given by participants and these responses must be accepted without further "fishing" (Gass & Mackey, 2000, p.154). The use of non-directive questioning precludes the possibility of "leading" the participant. Being vigilant to avoid the possibility of "putting ideas" (Gass & Mackey, 2000, p. 154) into the heads of the participants is important for rigorously valid and reliable data because, without such a focus on neutrality within questions, participants may extrapolate an issue that they feel is of relevance to the research and researcher but was of little consequence to them at the time of the activity.

Maintaining non-directive questioning can be difficult because an interviewer may unknowingly put participants in the position where they are trying to meet unstated expectations. Participants may also provide "here and now" responses created from their understanding of what they believe they should be saying (Nisbett & Wilson, 1977) or what they may have just thought. An example of a "here and now" response, from Chapter Five, was a comment by Pamela during a pause in viewing the video of the previous day's robotic activity, "Looking back on the tape, I've made a value judgement". This clearly indicates a thought that is occurring from the present consideration of what happened during the previous activity. "Here and now" responses, as opposed to the required "there and then" responses, are not usable and have to be discarded from analysis. Patience is required, particularly with young participants who want to please adults with what they might like to hear.

Henderson and Tallman (2006) found, when working with teacher-librarians and students from Grades Four through to Twelve, that they had a "greater likelihood of obtaining a more thorough recall of what the participants had been thinking" (p.79) if both the participant and the interviewer initiated pauses in the video at appropriate places. Researchers can pause the video playback if they are looking for thoughts on specific interactions containing "implicit [positive or] negative feedback" (Gass & Mackey, 2000, p. 53), such as a response to a particular participant's facial expression. Participant pauses may uncover unanticipated, yet enlightening, data that may otherwise be missed if participants are not given the opportunity to initiate them.

Value of protocol change..

Adhering to the strict protocols of this methodology maximised the validity and reliability of data. Nevertheless, a variation to one of the protocols was seen to be necessary with this group of student participants after the first round of stimulated recall interviews elicited insufficient responses to satisfy data requirements. The researcher had recorded in her journal: "interviews not providing the recalled thoughts and feelings required for comparative study" (Researcher's Journal, 16 May 2005; Appendix S). This journal entry prompted changes to address the deficiency.

The open-ended question, "What were you doing then?", to prompt a participant to verbalize what they had been doing prior to explaining what they had been thinking, was utilised. While an intensive search of the literature failed to find the inclusion of the priory question, "What were you doing?", at the time the change was implemented, subsequent references to its usability were found. One was tucked away in the appendices of Marland et al.'s (1992) text. Of more significance were two earlier occurrences. Research by Hafner (1957) and Mayzner, Tresselt and Helbock (1964), although of some maturity now, found increased responses when they asked their subjects to verbalize what they were doing and, next, thinking. This inclusion of a "What were you doing?" prompt was unknowingly resurrected because it was judged a likely solution to redress the paucity of responses. Students' recall was enhanced, yet remained uncontaminated.

The substantial changes in the number of useable responses and no thoughts that occurred from implementing this change to the protocol from the first stimulated recall session (SR1) to the second (SR2) are illustrated in Table 3.7.

Table 3.7: Number and Percentage Change in Responses after Protocol Change.

Student	SR1 Number	SR2 Number	Percentage change
	Usable Responses		
Jayne	43	47	9%
Ellen	42	54	22%
Sam	31	54	43%
Jim	27	35	23%
	'No Thoughts' Response		
Jayne	14	6	-57%
Ellen	74	14	-81%
Sam	67	28	-58%
Jim	30	12	-60%

Note:
SR1 = Stimulated Recall Interview May; SR2 = Stimulated Recall Interview July 2005

Results also indicated that the quality of response improved as well as the quantity of responses (Table 3.7). Richer mental models of procedural knowledge, that is, the steps they were taking to address problem-solving situations, were expressed by the students in the second interviews. Crucially, students' conceptual knowledge, articulated through their descriptive responses to questions about the way the system and its components worked, were evident not only in the July SR interviews but also in their July journaling. The importance of the resurrection of this protocol within stimulated recall methodology was further enhanced by the constancy of three variables in each of the two stimulated recall episodes: context, participants, and setting.

Teach-Back and Teach-Back Interviews

"Teach-back" is a technique for studying the procedural (van der Veer, 1990), conceptual (Barker, van Schaik, Hudson, & Meng Tan, 1998), and reflective (Jonassen, 1995) knowledge that participants have in a domain. The process of using teach-back episodes to obtain data usually involves participants having some initial exposure to the target system or domain. Once participants have acquired a satisfactory understanding of the system, they are asked to either describe, usually on paper, the performance procedures (Barker, van Schaik, & Hudson, 1998) or teach (Jonassen, 1995) another person who has had little or no exposure to the system. The participant "expert teachers" should be able to "teach" the novice pupil enough about the system and its components so that the latter can gain an overview of the system's process or be able to perform some predetermined tasks with the system.

Such teacher participants who conduct the teach-back episode use their own language and mode of representation to teach their novice student. Snow (1989) recognised that teaching and learning involves a progression from simple mental models to more complex mental models within a domain, thereby indicating a hierarchical structure (Newton, 1996). The process and content of the students' teach-back should reflect this progression of simple to more complex and not be limited to incidental or informal knowledge (van der Veer & Peurta-Melguizo, 2002). It is important that the student "teacher" participants are aware that it is they who control that progression. How the teacher participants create their instructional task could reflect their personal learning strategies (Newton, 1996; Barker, van Schaik & Hudson, 1998; Snow, 1989) or the engagement of multiple strategies (Kyllonen, Lohman & Woltz, 1984; Siegler, 1989).

The sessions were observed, recorded, and later analysed for different aspects of mental models, completeness, and correctness (Barker, van Schaik & Hudson, 1998) and how much elaboration and personalisation of the process (Snow, 1989) were evident. Early use of teach-back discussed by Snow (1989) established how much paraphrasing the teacher participant used and the degree to which sequences within the domain were reorganised, as this indicates conceptual mental models. In this study, such conceptual mental models would also be evident in the separate yet synchronistic domains of programming of the software for robot instructions and construction of the physical robot for compliance with those instructions. One of the strengths of teach-back is that it is a procedure that can be used easily in the classroom across all subject areas (Snow, 1989). This study's use of teach-back proved that it strengthened the reliability of the research by supplementing individual data collection methods with a method that provides opportunities to exteriorise the mental models utilized by students when teaching and learning about robotics.

Each of the four student participants (Table 3.3) were asked to teach another student of the same age how to use the robotic equipment to complete Pilot One of the Lego™ Dacta equipment and Robolab™ software. Their four learners had had no prior experience with robotics. Each 30 minute teach-back episode was held consecutively and was observed by the researcher who took notes of the interaction between the "expert teacher" and "novice student". An example from the observation notes is, "Axel can't separate the two small blue pieces so he finds a yellow piece with two small blue pieces already on and gives it to Sam" (Teach-back session, Sam, 3 October, 2005).

A short, five to 10 minute interview with each of the novice students (Appendix V) was held privately to determine their perceived level of confidence in their learning with respect to their ability to work with the system following their lesson. This and other interviews adhered to the ethical conditions implemented for children (Ethics section, this chapter). This interview was conducted without the "expert teacher" being present so as to ensure that the novice student could respond honestly. A longer interview of 10 to 15 minutes was then conducted with each expert teacher participant (Appendix V), to determine why they used particular teaching techniques and strategies and how confident each felt that these strategies enabled the novice student to learn.

The data collected from these episodes were coded for mental models of declarative knowledge, procedural knowledge, conceptual knowledge, predictions of success, pedagogy, cognitive processes, student learning, and assessment. Of these mental models — pedagogy, cognitive processes, student learning, and assessment — were only previously coded in the classroom teacher's interviews. The teach-back episode provided the opportunity to reveal the mental models that students run when exposed to a similar teaching/learning situation to that of their teacher. In some ways, the neophyte teachers had an advantage over their teacher in that their semiotic and semantic language matched that of their students. This should enable the linguistic aspect of the mental models, that they were helping to create in their students, to be constructed more effectively for this domain.

Questions, such as the following, were entertained (Researcher's Journal) by the researcher in the preparatory phase: Would they engage or create mental models of their own personal learning strategies to teach (Snow, 1989)? Would they engage multiple strategies (Kyllonen et al., 1984; Siegler, 1989) to ensure their student had the best opportunity to learn? Would they imitate their current teacher or previous teachers' strategies? The inclusion of this data collection method added depth to the study and provided the student participants with another avenue to develop and exteriorise their mental models.

Teach-back also provided a new adventure for the students in the same vein that Gandalf presented Bilbo with a novel voyage of discovery. The creation of a dynamic teaching episode, as this thesis demonstrates, also provides fertile ground for short, structured, researcher-conducted interviews (e.g., Appendix V) with participants who adopted the role of "expert teachers", and those who were "novice students" after each teach-back episode. These interviews (Table 3.3) were conducted in order to determine various mental models subsequently coded from the interview data. Such mental models are significant as they would be expected to guide the "expert teacher's" lesson as exemplified through their chosen teaching strategies. The "expert teacher's" mental models would also guide the learning process for the novice through the application of effective problem-solving strategies.

Participant Journals

Journals provide an opportunity for research participants to reflect on their performance, concepts, interactions, and involvement in a project. Journals are more a part of naturalistic approaches (Babbie, 2007; Rutherford & Wilson, 1992) rather than the ethnomethodological approach. Rather than "identifying the methods through which understanding occurs" (Babbie, 2007, p. 296) and imposing a particular regime on the participants, they enable the participants to write and/or record in pictures and/or words their interactions with a subject, such as robotics, as they understand it. Regular journal writing, either with or without the guidance of a provided structure (Rodrigues, 2010), allows individuals to create a personal space in which to express themselves in a number of ways.

However, limitations can occur with journal writing (Burns, 2000). Journals can be a time-consuming artefact to compile and their contents may be incomplete if time constraints are not addressed (Burns, 2000; Rodrigues, 2010) in order to allow each journal author sufficient time to record their entries. Students and, indeed, some adults may have language difficulties that preclude them from recording their ideas, thoughts, and reflections in the fullest terms. While the journal or diary is a log that often focuses on specific events, such as robotics, it is not uncommon for "inflation" to occur where the modification of behaviour may come about in order to create a favourable impression (Burns, 2000). Timetabling particular times to do the recording may be problematic as some concepts are formed well after the event and, at times, may not relate to the actual activity undertaken.

While interviews and questionnaires used for data collection are conducted at specific times, it is the journal entry done on a weekly basis that has the potential to provide an ongoing record of events from each participant's perspective. If the researcher was required to be present each time a journal entry was recorded, such attendance could be an impractical strain on resources (Burns, 2000). Nevertheless, it is journal entries, recorded throughout the length of the study, that provide a personal description of the individual's journey.

Students' journal.

The student participants (n=24) were asked to record particular responses at particular times throughout the study by their teacher. Pamela had collaborated with the researcher to create a set of probes that were relevant both to the classroom formative assessment and to the research. These probes, shown in Table 3.8, include prompts, either a specific question or a “sentence starter”, and were written on a white board at variable times, as indicated, for students to copy into their journals and then to complete. Weekly entries were also made by the students.

Table 3.8: Student Journal Entries

2005 Date logged	Set by	Journal Question and Starter	
23 March	T/R	1.What is a robot?	
		2.Why are they useful?	
20 April	T/R	1. The things that I am most worried about in making a robot include …	
		2. The things that I am most looking forward to in making a robot include …	
26 April	R	1. How does the computer speak to the robot?	
		2. Why does the RCX# need software?	
3 May	R	1. The things I remember most from my first experience with making robots include …	
6 June	R	1. The activities I find most enjoyable include …	
7 July	R	1. What I am finding difficult is …because …	
		2. This could be solved by …	
9 August	R	1. I could improve my robot’s function by …	
		2. The computer program used to program the robot is easy/difficult to use because …	
2 November	T	Names of members in your pair _____ , ______	
	T	1. Who worked the hardest in your group?	
	R	2. What showed your experience was successful?	
	R	3. How can you show that you can work with robotics?	
	R	4. What is the best way to assess the robotics experience?	
	T/R	5. Why was your journal useful to you as a learner?	
Weekly lesson entry	T/R	1. Goals for the day …	(Pre lesson)
		2. What I achieved …	(Post lesson)
		3. What I plan to do next time ...	(Post lesson)

Note:
* T = teacher, R = researcher, T/R = both teacher and researcher
RCX # is the term used for the robotic “brick” that contained its own central processing unit (CPU) for the downloading of the program from the computer. Students, in the main, referred to the RCX as “the robot”. RCX was included in these questions because it was seen, by the teacher, as beneficial to replicate the use of terminology used in the robotics kit.

The journal provided students with opportunities to record their thoughts, beliefs, and perceptions — in effect, their mental models — on specific areas that reflected the categories of mental models that were being used in other data collection, such as semi-structured interviews and Likert Scale questionnaires. The journal entries (Table 3.8) required students to express their mental models about many themes, such as social construction and problem-solving, that provided data for triangulation (Burns, 2000). The students' journals were significantly important as an authentic source of rich information for both the researcher and the teacher.

The weekly lesson journal entries (Table 3.8), worded by the teacher, were an integral part of both the teaching/learning process and the research project because they reflected the students' goals and predictions of success by displaying their metacognitive awareness through self-evaluation. The final entries in November (Table 3.8), required the students to reflect on the way that the robotics project could be assessed and how they would show that they could use the program. These were added as the study progressed. The addition of these prompts gave the teacher some important feedback and provided the opportunity to triangulate the data being collected through other instruments, such as, the post-experience Likert Scale Questionnaire, the Teach-Back Episode, and the Focus Group Interview.

Teacher's journal.

The teacher's journal also provided a commentary on the experiences that she and the students were having, although particular journal themes or questions were not mandated by the researcher as they had been for the students. This lack of structure was to ensure that the teacher felt at liberty to record her individual, anecdotal reflections that would provide another authoritative perspective of the project. The teacher's reflections ensured that the researcher remained grounded in her approach to the project by reminding her that the learning implications were for the *entire* cohort of students. Most importantly, this was a real teaching and learning situation and not one engineered by the researcher for the sole purpose of obtaining data for a study. The teacher recorded her struggles with equipment, time, and class management and these background descriptions provided a fuller picture of the mental models she was retrieving, running, remodelling, and storing (Appendix U for example).

Researcher's journal.

The researcher's journal, tattered and pink, was filled with interesting anecdotes as well. While trolls and dragons were not encountered, the decision-making process when faced with an obstacle seemed just as complex as that instantiated by Bilbo Baggins as he sat outside the tightly-sealed doorway into Smaug's lair. There were times of entering unchartered territory and having but one opportunity to collect the data that would reveal the treasure of mental models. Coding lists, sample interview questions, complex analysis decisions, and notes from meetings were all written in the journal. Field notes were recorded for posterity, such as that recorded on 14 November, 2005: “Do not turn the camera sideways as the film tilts — a bad error by me!” The journal served as a vital tool and the strength of its usefulness became apparent when this thesis was being written. It enabled the availability of a vivid picture of the mental models exteriorised in real-time by the researcher.

Focus Groups or Distributed Cognition

Lewis’s (1992) work with 10 year old students, who were discussing learning difficulties, found that the students’ understanding of the issues were enhanced through a group interview situation where ideas were challenged and extended through interaction with others. Focus groups bring together participants who may hold different opinions (Cohen et al., 1995) and are advantageous because they provide an opportunity to expose such opinions so that all the participants are aware of what the others are thinking in terms of the activity (Watts & Ebbutt, 1987). Such an interview allows the participants to be interviewed “systematically and simultaneously” (Babbie, 2007, p.308).

One of the problems with conducting this type of interview is the likelihood of “groupthink” (Babbie, 2007, p.309), where participants in the group conform to the views of the most outspoken members. Another disadvantage is that group dynamics (Watts & Ebbutt, 1987) may make it difficult to follow a particularly interesting line of questioning instigated by one individual (Cohen et al., 1995). Other risks include the interviewer over-directing (Babbie, 2007) the interview or bringing their own views into play, either through nuances, such as body language and inflection, or what questions the interviewer allows to be extrapolated and which ones are not.

It is vital to recognise the benefits of managing such a complex interview. Other data instruments had included a focus on the individual and how their mental models matched or mismatched the mental models of others and are a norm in cognitive science (Banks & Millward, 2000). Both the situated-cognitive environment (Brown, Collins, & Duguid, 1989) of the robotics laboratory and the pairing of students by the teacher in that environment, facilitated the sharing of mental models in an authentic learning experience. (Rouse, Cannon-Bowers, & Salas, 1992).

Obviously, a focus group interview needed a focus. The day before, the four students were required to design an assessment task. The purpose was two-fold: one was to bring authenticity to the focus group interview and the other provided the students with an opportunity to be an assessor. They had already had experiences as a learner in the robotics laboratory and those of a teacher in the teach-back episode (Table 3.2). This formal experience, as an assessor, added richness to the students' experience and aided the determination of their mental models of authentic assessment content, process, and usefulness. The assessment session also provided another shared experience in addition to the students' laboratory experiences with robotics.

Each student was required to design a 30-minute activity for one of the other participants that would challenge them to demonstrate what each had learned about building and programming a robot. The activity could draw upon any of the pilot or training programmes they had undertaken, or involve an untried activity. The students were paired by having two students draw a name out of a hat. This draw was supervised by the researcher and another teacher not associated with the project. The pairs consisted of an assessor, who would design the activity and explain what was to be achieved, and the assessed participant, who would complete the activity. Five minutes was given for the participating assessor to prepare the activity and 25 minutes for the participant being assessed to complete the task. Roles were then reversed ensuring the participants had the opportunity to both design and complete a challenge.

The four assessment sessions were held in an hour-long period and interactions between each pair of students were videotaped and later transcribed. Except for timing prompts, there was no interaction between the researcher and the participants during this time. The two groups could not assist each other, either within pairs or across pairs, with completing the challenges.

Due to school timetable constraints, the group interview could not be conducted on the day of the assessment activity. Nevertheless, it was conducted the following day that was within 24 hours thereby enhancing accurate recall (Bloom, 1954; Gass & Mackey, 2000). The challenging events of the day before were then discussed in the semi-structured exchange (Appendix W) in order to investigate their mental models and the distributed cognition of those models. The focus group interview provided a research tool that would capture shared mental models about teaching, learning, and assessment and, in doing so, addressed Research Question 3 (see earlier this chapter).

The focus group interview provided a rich source of data after a slow start that saw the first 15 minutes being dominated by individual responses. As the context was new, it took some time for them to adjust to its novelty. It also took some time for the interviewer to realise the limitations imposed on the participants by asking closed questions. Persistence aligned with an adjustment of questioning style was rewarded because the interactions grew richer, as indicated in the following two excerpts from the interview transcripts. The first provides evidence of the early, limited interchange:

Interviewer: Does robotics allow you to be creative?
Sam: Yeah.
Interviewer: *Looks at other students and waits.*
Do you agree with that?
Waits for response.
Bree?
Bree: Yes.
Interviewer: *Looks at Jayne*
And you?
Jayne: *Nods her head.*

The second excerpt, with a more open style of question, demonstrates the dynamic interchange that followed in which students contributed with a tumbling eagerness that is lost in the rigidity of text:

Interviewer: Why is it the same, say, for Maths?
Bree: Um, say, if you did a test and you thought about that certain question, or that class, what you didn't know what to do that night, when you got the Maths test back you could actually know what it was, and how to do it.
Jayne: You could ask advice from your parents.
Sam: You could be assessed on the same thing.
Ellen: If you forget something you can, like, go home and try to figure it out. And then if you don't know, just ask your parents.
Jayne: Or you could ask your teacher when you come to school or something.

Thus, without prompting and with more open questioning, the focus group interview culminated in a "we-ness" or "us" collegiality of shared mental models (Anderson et al., 1996) that was relative to the social context (Bibby, 1992) of the semi-structured exchange.

The focus group interview added significantly to research in the field because such a methodology is rarely found in the mental model literature that includes young participants (Eronen et al., 2002; Kennedy & Trafton, 2007; Kiesler & Goetz, 2002). The focus group interview enables the determination of how students engage in “collective sense-making” (Wibeck, Dahlgren & Oberg, 2007, p. 249) and how the distribution of mental models (Johnson-Laird & Byrne, 1991) enables them to negotiate a social situation.

Coding

All interview data were analysed using “pattern coding” (Miles & Huberman, 1994, p. 69) (Appendix M). Pattern coding served four purposes for this study as proposed by Miles and Huberman (1994) and reinforced by Berg (2007). These were:

1. Reducing data to workable units,
2. Focussing the researcher on analysis during data collection,
3. Enabling the researcher to define the mental models being studied, and
4. Enabling cross-participant analysis for common mental models.

While first-level coding helps summarize data, pattern coding enables the grouping of those summaries into themes or, in this case, mental models. An example was Pamela’s assumption of the students’ mental models of robots and robotics. When categorised, her responses were marked with the code AS-MS indicating an assumption (AS) about the meta-ability of the students (MS). When the participants’ category cards were cross-referenced for matches and mismatches of mental models, this code was used to link to the conceptual knowledge (CON) and anthropomorphic responses (ANT) of the students.

The codes used for pattern coding grew from the categories established when the interviews were being designed. An example of the categories included in the interviews was Social Construction Issues. This incorporated various sub-categories (e.g., Predictions and Previous Experience) designed to delineate a variety of mental models of working collaboratively. The use of broad categories enabled the data to be organised into workable, comparable units with the subsequent specific focus on particular perceptions within that category.

Category cards (Turner, 1981) were created from the analysed data. These electronic category cards were cross-referenced to all participants and aided the clarification of how the emerging participants' mental models may have matched or mismatched with other participants in the study (Appendix N). The "commonalities" or matches were clearly evident in the category cards because the data had been coded, categorised, and refined in a systematic method.

Maximising Validity and Reliability

Strengths of the study contributed to the maximisation of validity, reliability, and credibility through the:

1. variety of data collection methods;
2. number of data collection episodes;
3. richness of relevant data on the mental models held by participants during the learning experiences;
4. unique longitudinal aspect of the data collection that included two data collection episodes:
    i. the first occurred 12 months after the beginning of the project and
    ii. the second concluded 20 months after the beginning of the project;
5. contribution to the field of cognitive research by resurrecting protocols in stimulated recall methodology by using "what were you doing…" as the first question rather than asked occasionally or not at all (see SR interviews section, this chapter);
6. development of a new data collection sequence where a participant-designed assessment episode preceded a focus group interview:
    i. an addition to the introspection mediating paradigm (see Focus groups then Distributed cognition sub section, this chapter);
7. triangulation (or, more accurately, multi-angulation) of data;
8. a robust paper trail for other researchers to follow and implement; and
9. spot-checking accuracy of coding/categorizing stimulated recall and mental models' data by an experienced researcher in these areas.

Maximising validity and reliability in mental model research involves multiple methods of investigation due to the complex nature of the mental models themselves. Mental models are created for a purpose and this is of particular importance when studying their effectiveness in lessons. Because mental models provide an "explanatory function for understanding the complexities in teaching and learning interactions" (Henderson and Tallman, 2006, p. 25), they may assist in the facilitation of assessment practices that both enlighten and guide teaching, learning, and assessing, particularly in design and technology. While mental models are internal structures (Johnson-Laird, 1983; Norman, 1983; Renk et al., 1994) particular to the user (Greca & Moreira, 2000), they can be "exteriorised" (Barker, van Schaik, Hudson, et al., 1998) when triggered by some stimuli or through interaction with a domain system (Carroll & Olson, 1988; Norman, 1983; van der Veer, 1990), such as robotics. This interaction results in some physical action or performance (Jonassen, 1995) that can be observed.

Conclusion

The journey made by Bilbo Baggins started with a plan that was designed by someone else and understood by few. He was continually required to construct, run, and reconstruct mental models for problem situations he had never encountered. His potential to do so successfully was overseen by one other, Gandalf, who wisely led but never interfered with the problem-solving strategies that Bilbo used. The whole journey was constructivism and social constructivism at its very best. The integrated nature of the entire journey provided a rich tapestry. This is how learning should be: exciting and challenging with a capable hand guiding the steps and occasionally holding the hand. Students can be challenged to find answers to riddles of robotics construction and programming. Within the participants in the study, "golden treasure inside [was] hid" (Tolkien, 1937, p.75) and it was the researcher's journey that unlocked that treasure.

The structure of this thesis follows, in chapter form, the application of the data collection methodology. Each chapter discusses what the data collected at discrete times indicated about the mental models held by the participants and how those mental models matched and/or mismatched others. Teaching and learning implications that evolved from those matches and mismatches are included in the discussion within each chapter. The decision to structure this document to follow the intervallic data collection episodes enabled the construction of an ever-increasingly detailed picture of the participants' mental models and how these were evolving.

Consequently, there is no distinct "results" chapter in this thesis. The analysis of the data has revealed rich mental models that cannot fit neatly into a separate chapter. Instead, the analysis of results, at each point illustrated in Figure 3.2, will be intertwined in the discussion of those mental models and their implications for classroom practice will be laid out as would a journey. Discussions along the way will also entail a full description of the implications of data collection methodology that was modified and adapted.

CHAPTER FOUR: *Pre-Experience Mental Models*

> We shall soon before the break of day start on our long journey . . . it is a solemn moment. (Tolkien, 1937, p. 17).

Introduction

The beginning of this journey by a teacher and a group of students into the unknown world of robotics was marked with cautious optimism and excited anticipation. This initial phase of the study involved establishing the participants' espoused mental models of robots, working with others, predictions of success, and solving problems that the participants held prior to any involvement with the Lego™ Dacta equipment and Robolab™ software.

The following chapter focuses on the participants' espoused mental models and demonstrates how different data collection methods can be triangulated (Miles & Huberman, 1994) to establish a clear picture of the participants' mental models. The data collection methods used to gather the pre-experience data on espoused mental models included Likert Scale questionnaires and journals for all 24 student participants and one teacher. Data were also collected from semi-structured interviews for the four student participants, reserve student participant, and teacher[1]. The quality of the instruments and the vigorous process of cross verification enabled a rich understanding of the participants' mental models. Each section identifies the collection methods used to obtain the data, the pattern codes used to engage the triangulation process, and an analysis of what the evidence reveals about the participants' espoused mental models.

Espoused Mental Models

Conceptual Knowledge

Robots and Robotics

A variety of areas relating to robots and robotics were investigated throughout the study. General conceptual knowledge, including comparisons between human and robot intelligence, have been maintained for the contribution these areas make to a deeper understanding of the students' espoused, and subsequent inaction and reflective, mental models that relate specifically to learning and the assessment of that learning.

[1] The reserve student, Bree, took Jim's place in the study when he left the school prior to the reflective semi-structured interviews in September 2005. See Chapter Three.

Robots and What They Do

In the two weeks prior to any data being collected from the students and any interaction with the robotic equipment, Pamela introduced some activities to expose the students to the type of computer experiences they would be having with the software and hardware in the robotics activities. She promoted these experiences as "play" initially, and then moved on to specific tasks that required the students to follow clear instructions.

Pamela explained in the Pre-Experience, Semi-Structured Interview held on 1 March 2005 that the students had not physically handled any Lego™ materials but "they've certainly done simulations a Lego™ simulation on the computer" [2] and had been introduced to the freeware, BlockCAD (Isaksson, 1993). This exposure "gave them a chance to just play with BlockCAD to see what they came up with" for a design of a robot. BlockCAD (Isaksson, 1993) is a simulation software program that enables students to select digitised blocks to construct artefacts in a variety of views. While the students are not programming, they are creating a three dimensional view of an artefact. Pamela was "just looking at what their perception of what a robot looked like". The students were also required to draw, freehand, what they thought a robot would look like at the same time they wrote their initial entry in their journal on 23 March 2005.

While these teacher-instigated experiences prompted students to consider the appearance of robots, it is highly likely that, even without any specific prompts being provided by the teacher, the students had formed their mental models from their personally-held concepts and previous experiences, rather than just from the shared experience in the classroom. While the teacher's individual views of robots was of interest, her assumptions of the mental models held by the students were of particular interest to this study. The interview with Pamela revealed her espoused mental model of how students of this age construct their personal understanding of the world. She believed that the students had little or no experience except for things they came across in real life. She admitted that she did not know if they had "any understanding of the relationship between human beings and robots. I think that they see robots as being an entity unto themselves". At this stage of the project she felt that their

[2] All interview quotes and data for Pamela were obtained from the Pre-Experience, Semi-Structured Interview that took place on 1 March 2005 and are not subsequently referenced in this chapter.

perception of a robot would be "a little bit human" but understood that they would have had different experiences.

Pamela's responses on *Likert Scale Questionnaire* items supported this interview espoused mental model of the students' perception of robots as shown in Table 4.1.

Table 4.1: Teacher's mental models of students' mental models of robots.

Pre-Experience Likert Scale Questionnaire: Teacher (10 March 2005)

	Strongly Agree	Agree	Unsure	Disagree	Strongly Disagree
16. Students will see robots as being more useful if they respond like humans				✓	
18. Students will see robots as more useful if they can talk like humans			✓		
19. Students would rather interact with a robot that his humanlike in appearance				✓	

Pamela expresses doubt regarding the students' perception of usefulness being linked to human-like responses or appearance. What is of interest is her uncertainty about how students will perceive usefulness in regard to the ability to speak like a human. Pamela's philosophy of education included constructivism (Derry, 1996; Mayer, 1996; von Glaserfeld, 1995) and social constructivism (Anderson et al., 1997; Smagorinsky, 2001; Vygotsky, 1978) that informed her mental model of child-centred pedagogical practice. This espoused mental model was evidenced by her belief that ". . . you can't move on to higher order concepts unless you've got the groundwork there. Kids have to have prior knowledge of something ... So we need to work from where the kids are at and build on it". Pamela admitted, that her assumptions of the espoused mental models students had, could be erroneous.

All students (n=58), who were in the class Pamela shared with another teacher in 2005, commenced writing in their *Journals* on 23 March 2005. The first question they were asked to respond to was, "What is a robot?" Pamela had not held any formal discussion about the nature of robots with the students prior to the journal writing episode. The journal responses by the 24 participants in the research project are shown in Table 4.2.

Table 4.2: "What is a robot?"

Student responses	Number of responses* (N=34)
Robots are:	
Mechanical	10
Electric	9
Programmed	6
Human-made	5
Metal	4

Note: * Some students gave multiple answers.

There seemed to be no confusion as to the mechanical, human-made nature of robots because there was no reference to human-like characteristics, such as "brain", "thinking", or "emotion". One quarter (N=6/24) held a clear mental model of "how" a robot operated by stating that it was "programmed": an indication that they held a mental model that a robot is created by humans and given instructions in some way.

When Pamela and four student participants were interviewed[3], several questions were included to enable triangulation among the data collection instruments. The questions of particular importance to this section were those pertaining to robots and robotics. The four students were asked what materials they believed were required to make a robot and their responses included items such as "wiring, motors, computers, metal, aluminium, batteries, Lego™, and tin". The inclusion of these materials supports the data from the *Likert Scale Questionnaire* and the students' *Journals* that indicate their espoused mental models contained no confusion as to the construction of robots and that they had non-human components.

However, there may have been some perplexity about what robots actually do to be of use. The entire group of students were also asked, at this time, to respond in their *Journal* to the question, "What actions do robots do?" Forty-seven responses were given by the 24 students and their responses are shown in Table 4.3.

Table 4.3: "What actions do robots do?"

Student responses:		Number of responses* (N=47)
Robots:	Obey instructions	16
	Move	16
	Talk	8
	Walk	3
	Pick up things	4

Note: * Some students gave multiple answers.

[3] Students' semi-structured interviews were held on 10 March 2005 with Ellen and Sam, 11 March 2005 with Jayne, and 13 March 2005 with Bree.

The results of the open-ended question about "What robots do" indicate that 16 students were aware that instructions given to robots are "obeyed" in some way. The other responses extend this "obeying commands" response and include the requirement of robotic movement and communication. Sixty-seven percent of students held an espoused mental model that included robots responding to instructions and moving in some way with 33 percent including the robot's action of "talking". None of the students' mental models that were exteriorised in the journals included robots fulfilling work roles. This lack of response contradicted Pamela's assumption that students may have espoused mental models of robots working in construction or motor vehicle assembly.

Neither of the two initial questions, shown in Tables 4.2 and 4.3 (1 in *Interview*; 1 in *Journal*), about robots was included in the Pre-Experience Likert Scale Questionnaire as the questions required a descriptive, individual response. A fuller picture was provided through the next journal question that asked about the usefulness of robots (Table 4.4).

Table 4.4: "How useful are robots?"

Student responses	Number of responses (N=32)
Robots are useful because they:	
o do house chores	7
o do what they are told	7
o help	4
o can be trained/programmed	3
o do things we don't want to do	2
o do things we can't do	2
o talk	1
o listen	1
o move	1
o never run out of energy	1
o make you happy	1
o are a friend	1
o will rule the world	1

Note: * Some students gave multiple answers.

The students' mental models (Table 4.4) also contradict Pamela's espoused mental models regarding robots working in factories or in motor vehicle assembly. The only specific work related tasks that the students included in their responses were household chores. Four different students espoused quite sophisticated mental models as they included robots being used to accomplish things humans cannot or do not want to do. While even these mental models do not equate to the specificity of Pamela's assumptions, they do indicate that the students understand the functionality of robots in everyday working life through the recognition of their capacity to undertake onerous or difficult tasks. The responses reflect the perspective of a child and the mental models of their affective domain (Barchi et al., 2002) as much as their cognitive domain.

The four individual *Pre-Experience, Semi-Structured Student Interviews* did not uncover any discrepancies in the answers of usefulness but they enabled multiple responses. These repeated the "domestic" view of the usefulness of robots to humans: household chores (4), work (3), and helper (3). Other responses included toy (3) and friend (3). In comparison, no journal entries included a reference to "toy" although one student, Fletch, who was not an interviewee, reaffirmed the idea of a robot being useful as a friend (Table 4.4).

The question of usefulness had been addressed on 10 March 2005 in the *Likert Scale Questionnaire*, and provided a means of triangulating the data (Table 4.5).

Table 4.5: Student responses to Pre-Experience Likert Scale question about robots

	Strongly Agree	Agree	Unsure	Disagree	Strongly Disagree
6. Robots should be able to do more than one thing.	20	4	0	0	0
17. Robots should move and act like humans to be useful.	9	9	5	1	0
24. Robots have brains that are similar to ours.	2	8	7	5	2

These responses should not be surprising given the nature of the "usefulness" that the students described two weeks later in their journal entries (Table 4.4). The fact of "moving" and "acting" like a human would enable the robot to accomplish tasks that are involved in household chores and homework activities. Of interest is the one negative response to this statement. Venson, a boy who was not one of the students participating in the semi-structured interviews, disagreed with the statement. His *Journal* responses on the usefulness of robots included the act of "helping" and "making us happy" that do not, by definition, require the robot to either move or act like a human. Quite possibly Venson may believe that a robot needs to move and act like a "robot" (not a human) to be useful! However, it is evident that, in general, the espoused mental models that the students were bringing to the learning experience included the concept that the usefulness of robots was positively related to human-like movement.

The espoused mental model of robots needing to be able to do more than one thing was also evident from responses to Item 6 in Table 4.5. This question was included because many automated machines in the house, to which children are exposed, are primarily responsible for carrying out one task. For example, an automatic dishwasher washes the dishes and a robotic vacuum cleaner vacuums the carpet. All 24 students responded in the affirmative with 20 of them agreeing strongly (Item 6, Table 4.5). This espoused mental model students held of the multi-tasking ability of robots was seen in the journal entries illustrated in Tables 4.3 and 4.4 where multiple answers were provided to the probes about what actions robots do (N=47) and how robots are useful (N=32).

While the students might not be aware of having experienced the reality of a robot in their lives, their espoused mental models were quite clear, if not limited, in demonstrating what they believed robots could do to be useful. It is also highly likely that their espoused mental models on the usefulness of robots were informed by television cartoons, computer/video games, and cinematic films rather than real-life experience in workplaces given their childhood experiences. While this research does not wish to address the specific influence of the media it acknowledges its influence in the formation of our mental models (Barker, van Schaik, & Hudson, 1998).

Robotics – Programming and Intelligence

A study by Chaminade, Hodgins and Kawato (2007) used computer-animated characters to investigate social cognition within brain function and the ways in which anthropomorphism affects such perceptions. The concept that “artificial” intelligence, as opposed to human intelligence, can guide the investigation into neural operation has a cyclical relativity that challenges the basic notion of the “artificiality” of artificial intelligence. It would seem that the “intelligence” engineered into robots or computer-animated characters, such as Gollum in the movie, *The Lord of the Rings* (Jackson, 2001/2002/2003), may have to be exhibited in an acceptable way to users so that their mental models of that technology embraces its functionality. If it is acceptable, then the “artificial” may not be artificial at all — it is human-engineered and based on human responses so, therefore, could be termed engineered intelligence. In this study, it was important to uncover the programming experiences and espoused mental models that the students had of such engineered intelligence so as to determine a base line for future comparison.

Pamela's espoused mental model of the students' mental models of robotic programming included the assumption that they had had no previous experience at programming, designing, or building a robot. These mental models were coded as AS-MS PRO (Teacher assumptions about students' meta-ability in programming/procedural knowledge). Pamela had ad hoc discussions with various students about their experiences with robots and this had informed her mental models. The students were aware of their forthcoming activities with robotics and showed interest and enthusiasm for the activities. They had been able to "play" with the simulation software, *BlockCAD* (Isaksson, 1993) to design their own version of a robot. But, appearance is not function! However, the characteristics of a robot's physicality might inform its functionality and, hence, how it is programmed.

The Pre-Experience *Likert Scale Questionnaire* (10 March 2005; Appendix E) challenged the students to think about the function of robot intelligence by asking them to compare a robot's "brain" to that of a human. This was one of the items that posed a statement that required a negative attitudinal response for the technically correct answer. In other words, a strongly negative response would indicate that the student had a functional mental model of robot intelligence. The results of the question, shown in the responses to Item 24 in Table 4.5, indicate that there was some uncertainty as to the equivalence of brain structure. These results indicate that fewer than one third of the students held espoused mental models that differentiated artificial or engineered from human intelligence. Of these seven students, only two strongly disagreed, indicating that they were very certain about the difference. While there may be some semantic discussion about the word "similar" in the question, the result indicates diverse espoused mental models.

The Pre-Experience, *Semi-Structured Interviews* (1-13 March 2005; Appendix I) provided an important source of triangulated clarification for this concept. Conducted with the students prior to any engagement with the robotics equipment, but subsequent to their experiences with the BlockCAD (Isaksson, 1993) simulation software, the interview responses indicated that students brought with them espoused mental models about robots' thinking and intelligence or programming (Table 4.6).

Table 4.6: Pre-experience semi-structured interview responses to questions about thinking and brain function of robots.

Student	Response
Bree	Memory chip
Ellen	Humans learn it just by being there but watching other humans do things
Jayne	They don't have a brain like us and they can't really speak
Sam	Artificial intelligence – computer for brain

The responses indicate that these students understand that robots do not think or communicate "their" intelligence in the same way as humans. The inclusion of the terms, "chips" and "computer", demonstrates that the espoused mental models contain functional concepts of the need for input and storage of human-to-robot communication. Ellen's comment of how humans learn by "just being there" demonstrates that her mental model of brain function for robots includes their need for the provision of specific instructions or commands. She is comparing the socialisation of humans and the socio-cultural (Vygotsky, 1978) way in which humans learn many of their skills and much of their knowledge — by "just being there and watching" — to a robot's requirement for a dedicated communication strategy that gives specific instructions.

Robots Summary

Students revealed espoused mental models of robots as being "mechanical" and capable of doing tasks, but without a clear delineation of the common functions of robots in society. Robots "help" but they can also be a "friend" and/or someone to do "things that we don't want to do" such as those robots seen in movies and on television. The lack of "toy" response suggests that the students' espoused mental models could be influenced by the association with work due to the school being the setting of the investigation. One student, Sam, who believed robots will "rule the world" (Table 4.4), was the only student to reveal an espoused mental model of robots that indicated he may have had more exposure to experiences that have enabled him to develop richer espoused mental models of robotics.

Pamela's assumptions about the students' mental models mismatched the students' mental models. She made a pragmatic observation, during the *Pre-experience, Semi-Structured Interview*, admitting that she would not really know what the students held in their mental models about robots and what robots do, until they started interacting with the equipment and program. She acknowledged that they would be operating from a variety of diverse backgrounds and experiences that would not enable her to make an accurate prediction of the espoused mental models they were bringing to the activity.

Social Construction

A Shared Learning Environment

Socio-cultural pedagogy proposes that much of our knowledge is socially rather than individually constructed (Berger & Luckman, 1967; Salomon & Perkins, 1998; Vygotsky, 1978; Windschitl, 2002). Similarly, while individually created, mental models are products and processes of our social, physical, and emotional interactions with our environment and our internal and external dialogues (Cronje & Fouche, 2008; Johnson-Laird, 2004; Johnson-Laird & Byrne, 1991; Vosniado, 2002). Mental models are externalised through the somatic expression of the individual that may include discussion, debates, writing, and facial expression. While most classroom activity is individual, many occasions occur during the day where students are sharing resources and space that oblige them to share their mental models with each other, either consciously or unconsciously, as they operate and learn within the social systems of the classroom.

In general, students working with information systems, like the robotics program in this study, extract what information they need from their environment to operate that system effectively (Cronje & Fouche, 2008; O'Malley & Draper, 1992). As novices, they depend less on internalised representations than they do on resources that are in the world (Norman, 1988), such as other students and instructional text. Two kinds of instructional text were available to the students in this study: hard copy booklets that accompany the Lego™ Dacta equipment and digital help guides embedded in the Robolab™ computer software.

The students were going to be working very closely with each other on a new system that required problem-solving strategies to be used in at least two domains: the computer program and the robot construction. The pre-experience data collection aimed to establish the espoused mental models of social construction that they were bringing to the experience.

The *Pre-Experience, Semi-Structured Interview* with Pamela, on 1 March 2005, revealed her espoused mental models of the students' mental models of social constructivism. She understood that “some students [are] naturally inclined to be individual workers … by nature, intrapersonal” while there are “those who are interpersonal by nature [and] will work very well in groups”. The significance of this mental model would be that she would be “careful which students I actually pair up”. The students would be working in pairs throughout the experience and Pamela felt that, for them, it was “important to understand why the partnerships are being put together” while also understanding that “decisions are imposed on them in life” (Student Participants section, Chapter 3).

The interview also uncovered the espoused mental models that Pamela held of her role in her social constructivist classroom. While being the guide on the side in Vygotsky’s (1978) Zone of Proximal Development, she would be assisting the students through their range of learning potential (Smagorinksy, 1995). Pamela also emphasised that “the students and I are certainly in that partnership together and we’ll be learning together”. Pamela’s espoused mental model of students learning in her classroom environment also reflected constructivism (Derry, 1996; Mayer, 1996) where the students would be active in selecting, organising, and integrating the forthcoming experiences with their existing knowledge in order to create new knowledge in the form of mental models in long-term memory. She believed that:

> the students are on a journey to discover for themselves, with support, what robotics is. Which is not just their other perceptions, but to actually learn by doing and, by experiencing it, that they’re actually going to discover what robotics is (Pamela, Pre-Experience Interview, 1 March 2005).

Pamela’s use of the shared journey or partnership theme was evidence of her mental model of learning that saw the learning experience as one of shared discovery.

The students’ espoused mental models of how they would be sharing this journey were of particular interest to Pamela and, of course, this research (Table 4.7).

Table 4.7: Student responses to the Likert Scale questions about social construction

	Strongly Agree	Agree	Unsure	Disagree	Strongly Disagree
12. I learn more when I work in a group.	11	6	5	1	1
13. The robot I make with my group will be better than the robot I would make alone.	7	10	1	3	3

In the *Semi-Structured Interviews* the four students interviewed replicated their questionnaire answers where three agreed and Ellen disagreed that they learned more in a group (Item 12, Table 4.7). However, Bree added a qualifier that she learned more in groups, “some of the time”. Vygotskian (1978) theory stipulates that interaction with a more capable other results in the social construction of knowledge. By association, the successful completion of a task occurs as the mental models of each participant are run, shared, and stored for future use. Anderson et al.’s (1996) research suggests that mental models that are shared are superior in effectiveness when being jointly run than any of the individual’s mental models. However, the success of working with others is rarely determined by the effectiveness of the participants’ mental models.

Success is often determined by the quality of the product that is produced or the correctness of the solution found by the group. The *Pre-Experience Likert Scale Questionnaire* used this perception with respect to Item 13 (Table 4.7). In other words, they were being asked to quantify the possible effectiveness of their robot construction in terms of these two distinct learning situations. This questionnaire was completed prior to any engagement the students had with the robotics equipment and prior to the formation of their “pair”. Item 13 in Table 4.7 shows most responses to this question demonstrated positive social constructivist mental models.

Of the four interviewed students, Ellen disagreed and Sam ticked “unsure” on the questionnaire (Item 13, Table 4.7). Ellen’s response supported her espoused mental model of working with others as she offered, “I’d kind of rather work by myself because sometimes, when you’re in groups, people talk too much and you never get things finished” (Ellen, Pre-Experience Interview, 10 March 2005). Ellen may have felt greater social responsibility (McInerney & McInerney, 2006) for her group members than they may feel for themselves or others when working in a group situation. Her mental model was also influenced by her sense of self-efficacy illustrated by her desire to complete tasks.

The *interview* responses to questions about working with others also provided the opportunity to qualify further the espoused mental models students had of working with others and are delineated in Table 4.8 (see next page; Questions Appendix I).

Table 4.8: Semi-structured interview responses to group work.

Working with others means:	Number of responses
o fixing problems with help	4
o [it is] easier	3
o [it is] quicker	2
o [the answer is] better	2
o teamwork	2
o [others] talk too much	1
o [we] don't finish	1
o [we] fight	1
o [I] get frustrated	1
o [I] get distracted	1
o [I] let the team down	1
o [they are] disobedient	1
o [making] sacrifices	1
o [the work is] slower	1
o [others are] interrupting	1
o [it is] hard	1

Note: Responses were grammatically augmented in [ ] to aid clarification without distorting the meaning

There appeared to be quite a difference in the responses from the students interviewed to the responses in the *Pre-Experience Likert Scale Questionnaire* (Table 4.8). This is indicative of the opportunity semi-structured interviews provide for thinking and responding in depth to questions. Here, they revealed their espoused mental models of the concern they may experience through pro-social behaviour (Wentzel, 1991) where how effectively the students work in groups to solve group problems is both an outcome and an antecedent of such behaviour.

There were 13 positive responses from the four students interviewed that displayed a little homogeneity while their negative responses to working in groups were heterogeneous, evidenced by the single responses. While social interaction can promote positive mental models of learning, students can obviously identify any negative influences that working within social groups can have on their problem-solving outcomes (McInerney & McInerney, 2006).

The *interviews* also pursued context-specific questions about the mental models of working with others to determine if the students shared or distributed their mental models during interactions or problem-solving situations. Table 4.9 displays pertinent responses that exemplify the range of answers to questions about working with others (Questions, Appendix I). The students seemed very eager to answer the questions in as much detail as they could and provided rich descriptions and expressions that helped create a richer picture of their espoused mental models.

Table 4.9: Working with others.

Student	Response
Bree	o That's hard, if you don't like the people that's [sic] in your group. If I had to choose who and what I was working with, and what I was doing, I probably would be successful in doing it that way. o The actual working in a group, it can be hard and it can not work out the way you want it to. o Or you can make sacrifices if it's needed [pause] or listen to the other person's idea and vote on what way it would go better.
Ellen	o Well, it will probably make it better and easier because you won't have to do everything. And you'll probably get your robot done quicker. o I'd kind of rather work by myself because, sometimes when you're in groups, people talk too much and you never get things finished.
Jayne	o I think it's good because you learn more and you're with [pause] If your friends are in the group you're in, it's easier for you because they might know more stuff than you and you can get more answers right. o When I'm in a group, sometimes it makes me a bit more slower [sic] because I have to help other people. o With some people you just want to get on with it and they need help.
Sam	o It depends on what I'm working on. It depends who's in your group, if you trust them or not. o Like they might say [pause] You might ask, like, how do you get, um, how do you get certain parts to move or something, and you may not trust the person with answers [sic]. o You complete what you're trying to work on. Build on teamwork.

The occasions when two or more people work together to solve a problem or create a solution, two or more mental models will be integrated through the "collaborative critiquing of a single shared mental model" (Henderson & Tallman, 2006, p. 45). This assumes that all parties are working towards a single transitory mental model (Anderson et al., 1996) through social constructivism. Studies (e.g., Anderson et al., 1996; Johnson-Laird et al., 1986) proposed that the ability to simultaneously manipulate and execute individual beliefs and mental models as new information is released between the parties requires adequate working memory capacity. If working memory is overloaded, as may occur with younger students who have not had the practice required to develop collaborative skills (Anderson et al., 1996), then the students may fail to complete the tasks.

This lack of satisfaction in completing group activities may explain why six of the 24 students in this study felt negatively toward having to work with others. As Sam explained, “It depends who’s in your group”. The students’ espoused mental models had developed from negative experiences, where they had failed to work on shared transitory mental models effectively, evidenced by Bree’s, “It can not work out the way you want it to”; Ellen’s, “People talk too much and you never get things finished”; or Jayne’s, “Sometimes it makes me a bit more slower [sic]”. Their evidence of the complexities of working in a socially constructed environment is of consequence and, therefore, of significance to teachers who consider social constructivist environments part of their pedagogical practice.

Predictions of Success and Assessment

An Assessed Learning Environment

The students in this study had been exposed to a variety of educational and recreational computer software programs from their earliest years at primary school. They would have gained some mastery over several but now would be entering a period of what Vygotsky (1978) referred to as “naïve psychology” (p. 93) or the period preceding such mastery of functional use of signs or icons with a new software program. Their predictions of the success or otherwise of such interactions were of interest. Bibby (1992) proposed that mental models provide the foundation from which students can reason about the strategies they will use for problem-solving and, while this occurs, the mental models serve “to eliminate condition redundancies in the problem-solving procedures that novices have” (p. 166). The efficiency of this mental model function is dependent upon the model-task match (Bibby, 1992) whereby a good match will enable more redundancies to be removed than a poor match. This section uncovers how the participants predicted their success with the Robolab™ software and the Lego™ Dacta equipment.

A prediction of the success of actions is an elementary function of mental models before, during, and subsequent to any interaction. Norman (1983) proposed that one of the major purposes of mental models was to enable a user of a system to predict its operation; to make an assessment of their success with selected actions.

One of the systemic advantages of the Robolab™ software and the Lego™ Dacta equipment (Chapter 3) is the use of iconic language and diagrammatic representations as shown in Figure 4.1. The accompanying support materials also included instruction booklets with icons and illustrations. Larkin and Simon (1987) found that using diagrams has semantic advantages over sentential representations. The interpretation of diagrams and icons effectively allows the students to link relevant mental models that access and run large amounts of grouped information for more efficient searching, the utilization of location information, and the support of perceptual inferences (Larkin & Simon, 1987).

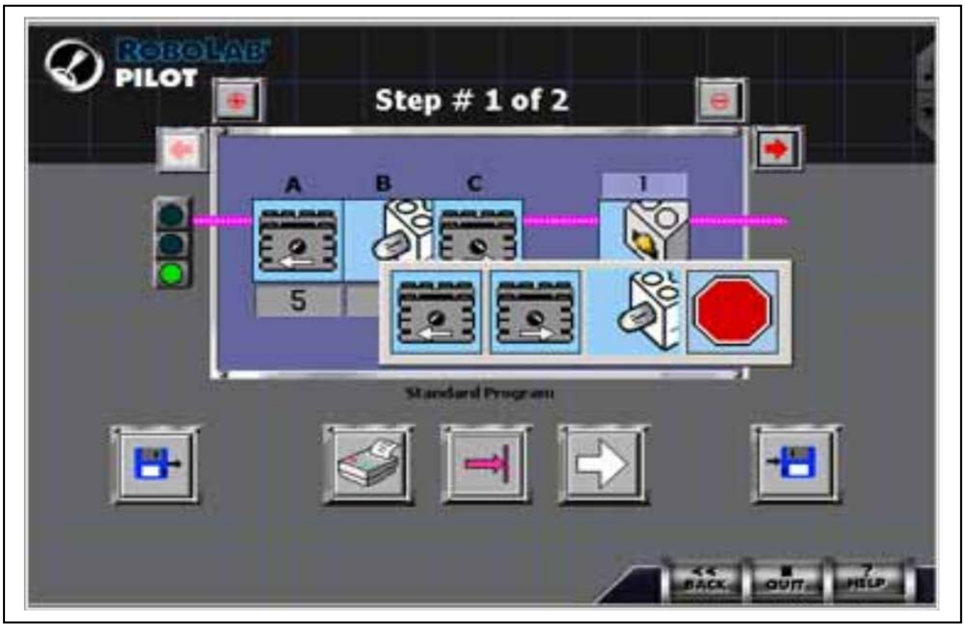

Figure 4.1. Screen capture of pilot program from RoboLab™ illustrating iconic language used to program robot. Image ©2010 The LEGO Group. Used with permission.

The *Pre-Experience Semi-Structured Interview* with Pamela revealed her assumptions about the students' espoused mental models of their likely success. She acknowledged that the students "have very little understanding of the process that it takes to actually get a robot to work. They have very little understanding of the two separate systems that do have to come together" (Pamela, Pre-Experience Interview, 1 March 2005). Pamela planned the students' introduction to the robotic learning experiences in some depth.

Prior to the study's commencement, Pamela developed a five-stage plan to introduce the cohort to the two systems:

1. What robotics is – definition;
2. Where robotics is applied – personally and in society;

3. System 1: Programming – iconic language and the purpose of symbols;
4. System 2: Constructing - putting the robot together; and,
5. Bringing the two systems together including relevant terminology.

Before the introduction of these stages, Pamela initiated student journal writing because she required them to record their progress and reflections throughout the experience as part of their robotics self-assessment strategy. She would introduce journal writing processes to small groups of students. Pamela's pedagogy reflected a social constructivist philosophy as she believed that students "learn by doing" and by "experiencing it" because, in this way, "they're actually going to discover what robotics is". While she was going to scaffold extra support for those who were finding the experience too challenging, she believed that the instructional material within the kits would provide adequate support for most students without relying on her to be "the" expert.

Before the robotic activities commenced, the students were asked to record their espoused mental models by predicting the possible outcomes of the experience in their *Journals*. Sentence starters were provided as part of the scaffolded support that Pamela offered as illustrated in Table 4.10.

Table 4.10: Student responses to class journal sentence starter, "The things that I am most looking forward to in making my robot include. . . "

Student responses	Number of responses
Make it do what I want	8
Make it dance	7
Make it move	6
Doing it successfully	6
Having fun	5
Adding music	4

The multi-answer format of the journal entry allowed the 24 students to record several predictions revealing more detail about their espoused mental models of working with robotics. Success or a sense of achievement without qualification as evidenced by the response, "doing it successfully", was recorded by six of the students (N=6/24, Table 4.10). However, most of the students qualified their predictions and anticipatory comments with concepts such as dancing, movement, and music. The implication of these responses is that the students were approaching the forthcoming activities with mental models of some level of success. The journals also provided the opportunity to establish any concerns that the students might have as they commenced the project.

The other journal entry about predictions, completed prior to the start of the activities, was prompted by a sentence starter (Table 4.11).

Table 4.11: Student responses to class journal sentence starter, "The things that I am most worried about when making my robot include. . . "

Student responses	Number of responses
Breaking it	9
It not working out	8
People laughing at me	8
Making it move	4
Making it the right way	4

Most students' espoused mental models appear to be influenced by learning goals (McInerney & McInerney, 2006) which means that the students' primary concern involved mastering a new area of learning and developing the skills to be successful by having it "work out" (N=8/24) by doing it the "right way" (N=4/24; Table 4.11). This focus on mastery goals is also evident in nine students' concerns about "breaking it", implying their espoused mental models contained a prediction of competence being required to manipulate the robotic materials.

Eight students' espoused mental models displayed a concern for performance or ego goals (McInerney & McInerney, 2006) where a sense of self-worth may be threatened if they were unsuccessful in front of their peers (Covington, 1992). Some of the precise terminology recorded by students who had concerns about "people laughing at me", included: "tease" and "making fun of me". These responses indicate espoused mental models that have been influenced by previous unsuccessful attempts at tasks that resulted in perceived derision by peers; an indication of failed assessment. The prediction of the success or otherwise of an educational experience can influence motivation more than the actual success that was experienced (Anderman, Maehr & Midgley, 1999) and so it may be of value to ensure that students are given the opportunity to realistically assess the skills they will need to complete a task whether in a group or on their own.

The *Pre-Experience Likert Scale Questionnaire* also asked the 24 students their assessment of the skills they predict will be required to make a robot and their responses are shown at Item 2 in Table 4.12.

Table 4.12: Predictions of the forthcoming robotics activity.

Pre-Experience Likert Scale Questionnaire: Students (10 March 2005)					
	Strongly Agree	Agree	Unsure	Disagree	Strongly Disagree
2. I have the skills required to make a robot.	2	11	9	2	0
7. It is fun creating robots.	12	6	6	0	0
11. Creating robots is challenging.	11	10	3	0	0
14. The way that I look at robots will change.	9	10	4	1	0

Thirteen affirmed they had the skills, nine were unsure, and two predicted that they did not have those skills. The question, “Could you make a robot?” (Appendix I), was repeated in the *Semi-Structured Interviews*, to gain further insight into the espoused mental models of predictions of success. Of the four students interviewed, two predicted that they could make a robot. These two students also agreed and strongly agreed, respectively, with the question on the Likert Scale questionnaire. Of the remaining two interviewees, one predicted they could if they had some help and the other was uncertain of their ability. Both of these students had selected “unsure” as their responses to Item 2 (Table 4.12).

In the *Pre-Experience, Semi-Structured Interview*, the students’ mental model of predictions of success were probed by asking a question using different terminology, “How successful will you be in making a robot?” This question prompted three of the four students to respond with uncertainty about their success. Two of these three students qualified their responses by predicting they *could* complete a programmed robot with *help*. The four interviewed students’ predictions about the forthcoming experiences were generally positive (Table 4.13).

Table 4.13: Students’ general predictions of robotics experience.

Student Interview Responses	Number of responses
Fun	3
Exciting	3
Learn about technology	1
Cool and new experience	1
Challenge	1
Creative	1
Interesting	1

Fun, proposed by three of the four interviewed students, was also mentioned by five other students in their *journals* on 20 April 2005 (Table 3.8, Chapter 3). The prediction of fun was also addressed in the *Pre-Experience Likert Scale Questionnaire* held prior to the interviews in March 2005 (Item 7; Table 4.12) and the responses support those in the semi-structured interviews (N=3/4). Bree was the only interview participant who stated, “It *probably* would be fun” in the interview and, consistently, was unsure in her response in the Likert Scale questionnaire.

The prediction of challenge was also part of the *Pre-Experience Likert Scale Questionnaire* (Item 11; Table 4.12). Ellen was the only interview participant who predicted robotics as a “challenge” in her Pre-Experience, Semi-Structured Interview (Table 4.13). It demonstrated the student’s recognition of the importance of risk taking with learning. She also predicted that robotics would be “creative” (Table 4.13) so her espoused mental model, while exhibiting uncertainty as to her skills to build a robot, included predictions of a challenging and creative learning experience.

Newton (1996) found that forced prediction required “moving passive learning into active learning” (p. 213). How students would look at the experience in the future, that is, their thoughts about robotics *after* the experiences was included and aimed to force students to make predictions; to engage their metacognitive awareness concerning changes that occur when learning activates new mental models in their problem-solving repertoire. Item 14 (Table 4.12) in the Likert Scale questionnaire proposed that the way they look at robotics will change after they have worked with the equipment. Nineteen students agreed that their concepts of robots would change after the experience, four were unsure, and one student disagreed. Norman (1983) proposed that an individual’s mental models contain beliefs of certainty or uncertainty about their knowledge. This perception may be influenced by how they recognise and apply the successful strategies for learning and problem-solving to interact productively with that phenomena: their metacognitive awareness.

Royer et al. (1993) expanded Glaser et al.’s (1985) discussion of metacognition by recognising several examples that included “being able to predict the success of one’s learning efforts” (p. 226). Item 14 (Table 4.12) did not seek to determine the students’ prediction of “success” of their learning in robotics. It sought to challenge them to enact metacognitive strategies to think about how their thoughts of a specific domain might change after a learning experience.

Bibby (1992) found that the unconscious processing of mental models not only allows students to solve problems but also involves a metacognitive function that is not unconscious; in other words it is a conscious function and, with training, can inform students of the success of their mental models and how they adapt to incorporate new experiences. Stripling (1995) contended that "real learning occurs only when these [mental] models are restructured to include new ideas in a meaningful context" (p. 165). It seems that the majority of students (N=19/24, Item 14 in Table 4.12) in this study understood that learning or experiencing the robotics program would change their perception — and their mental models.

The data from the three different methods (journals, questionnaire, and interviews) were triangulated to validate the evidence of the students' espoused mental models of success in building robots and confirmed the consistency of students' espoused mental models that illustrated some uncertainty as to their current skills to build a robot.

Making Mistakes and Problem-Solving

Trying a New Formula

The data collected on how the students responded to making mistakes when working was aimed at determining their mental models on problem-solving in unique environments. In effect, this was to determine how they looked back over their actions when they encountered a procedural error. Novices with the equipment, as first-time users, the students' mental models would be fundamentally different to those of an expert (Glaser et al. 1985; Henderson & Tallman, 2006; Holyoak, 1991; Newton, 1996). Simply put, an expert's mental model contains understandings and knowledge from many previous encounters within the domain (Henderson & Tallman, 2006; Newton, 1996).

The approaches to problem-solving are also quite different as experts use a greater repertoire of conceptual understandings and analogies while novices would be more dependent on formulaic progression to problem-solving (Barker, van Schaik, & Hudson, 1998; Henderson & Tallman, 2006; Newton, 1996). Sloboda (1996) further endows an expert with the ability to "make an appropriate response to a situation that contains a degree of unpredictability" (p. 108). Novices might find themselves relying on help from others as their preferred first option when facing an unpredictable situation. The pre-experience semi-structured interview with the teacher, Pamela, uncovered her espoused mental models on how the students would learn throughout the problem-solving environment of robotics.

The students in the two classes who were undertaking the robotics experience were yet to experience Pamela's teaching style that was guided by her mental model of learning. It included the philosophy of "learn by doing and by experiencing it" (Pamela, Pre-Experience Interview, 1 March 2005). During the *Semi-Structured Interview* Pamela commented that she was trying to get them to take responsibility for their learning. She continued:

> I truly believe that by doing it and by making their own mistakes and learning by their mistakes, by reflecting on what they're doing, by setting themselves new goals, that the learning that will occur will be [pause] learning that they will keep" (Pamela, Pre-Experience Interview, 1 March 2005).

She emphasised that "this [the robotics learning experience] is real learning, real problem solving". Pamela was not an expert at robotics and was not situating herself as one to the students as she reiterated from the beginning that they were on the journey together.

Being exposed to such a learning experience within a social-constructivist classroom would be a challenging experience for the students. They would be placed in novel situations and required to negotiate their way through problems they encountered without ultimate reliance on their teacher's capacity or willingness to provide answers. It was valid to determine what espoused mental models of making mistakes when problem-solving the students were bringing to the experience in order to see what changes would occur within these mental models as they moved through the learning experience.

The students were asked during the *Pre-Experience Likert Scale Questionnaire* if they believed they would learn more if given the opportunity to experiment with the robots. The hands-on, year long problem-solving nature of robotics was quite different from their other learning experiences at school. Their eagerness or otherwise to experiment with the equipment was an important starting point in determining the espoused mental models of correcting mistakes and problem-solving (Item 10, Table 4.14).

Table 4.14: Student responses about their forthcoming robotics activity.

Pre-Experience Likert Scale Questionnaire: Students (March 2005)					
	Strongly Agree	Agree	Unsure	Disagree	Strongly Disagree
10. I learn more when I can experiment with robots	11	10	3	0	0
16. I become worried when I make mistakes	7	11	4	1	1
28. I am more confident when I have the chance to correct my mistakes	17	7	0	0	0
29. You learn more when you fix your own mistakes	10	11	3	0	0

Although three were unsure, 21 students indicated that the opportunity to experiment was an essential part of their espoused mental models of problem-solving. This indicates that, particularly the latter's, espoused mental models should contain concepts that enable them to monitor their own cognition or use metacognition in order to learn more effectively (Brandt, 1986; Derry & Murphy, 1986; Flavell, 1985; Mayer, 1989; Schoenfeld, 1987).

The students were also asked three questions (Items 16, 28, 29 in Table 4.14) about the strategies they used when they knew they had made a mistake: the procedural knowledge they would use strategically and automatically to regulate their cognition and metacognitive awareness (Flavell, Miller & Miller, 1993; Schraw & Moshman, 1995).

Item 16 (Table 4.14) provided an indication of their strength of concern or worry when a mistake was made. While the predominant positive responses should signal teacher concern on initial appraisement, the next relevant question, Item 28 (Table 4.14), asked for responses about their confidence to correct mistakes. All students indicated that they were confident to do so if given the opportunity. This result indicates that, while they have concerns about initial success that may be exhibited through "worry", they believed that they had the skills and/or resources to deal with problems that might arise. This view is supported by the students' response to Item 29 (Table 4.14). Twenty-one students agreed they learned more when given the opportunity to fix their own mistakes and three were unsure. It would seem that most students held positive espoused mental models about their metacognitive control to work out their mistakes, realise the benefit of doing so, and want that opportunity. What will be of interest, as the learning experience progressed, is the degree of self-regulation that students applied to monitor their cognitive process and problem-solving strategies in order to judge their own progress (Butler & Wynne, 1995) in addressing the mistakes they make.

The responses to the questions about mistakes in the *Pre-Experience Semi-Structured Interview* revealed a variety of strategies that the four students had previously used and were anticipating using when encountering mistakes (Table 4.15).

Table 4.15: Students' strategies for correcting mistakes.

Student Responses	Number of responses
Try to fix it	4
Start again	4
Make it better	1
Do a plan	1
Change it a bit	1
Keep on going	1
Leave it	1
Have patience	1

The "try and fix it" and "start again" responses were valid answers. These indicate the students' espoused mental models of problem-solving contained the strategies that probably were taught to them by previous teachers. The "leave it" strategy was the only response that indicated a lack of possible solutions to solving the problem and was given by one student, Ellen, but only after she had responded with other strategies, such as "try to fix it" and "keep on going". This response indicated that, while she had pro-active strategies available within her problem-solving repertoire (Butler & Wynne, 1995), she also offered, pragmatically, that she might have to "leave" (Table 4.15) a problem if she had exhausted her repertoire.

Probes were also made with the four participants about what they would do if they needed help with constructing and programming their robot (Appendix I). Their responses (Table 4.16) were varied and indicated that their espoused mental models were created from previous problem-solving experiences where successful strategies had been used.

Table 4.16: Students' responses about where they would find help.

Student Responses	Number of responses
Research on computer or Internet	7
Ask someone who knows	3
Ask person in group	3
Teacher	2
Robot program help assistant	2
Adult	1
Experiment	1
Dictionary	1
Television	1

All students held a mental model that believed that utilising research strategies on, not merely looking at, relevant computer or CD resources or the Internet was a viable option to find help. The strategy of asking someone who knows did not necessarily mean asking the teacher as evidenced by their responses to ask someone in their group or another adult. The teacher was cited as frequently as the help assistant embedded in the robot computer software as a reliable source of information. While these two students had not, at the time of the interview, used the Robolab™ software, they were running their mental models of software help functionality to find a possible solution to anticipated problems. The students' responses also indicate that these four interviewed students, at least, did not necessarily see the teacher as the font of all knowledge. This acknowledgement supported the espoused mental model of the role that Pamela saw herself taking during her lessons. This was a powerful observation and may indicate the students' understanding of Pamela's role as a co-learner and/or their previous classroom experience of social constructivism/constructivism. The researcher noted, in her journal, the interest in whether or not their actions would externalise these espoused mental models during periods of challenging problem-solving that were ahead of them.

In Summary

The pre-experience data, described and discussed in this chapter, sought to expose the espoused mental models that all participants were bringing to the activity. Data were triangulated from Pre-Experience Likert Scale Questionnaires, Semi-Structured Interviews, and Journal entries in order to establish a clear picture of the participants' espoused mental models of robots, working with others, likely success, and solving problems. Each section described the data collection methods used and the triangulation, and discussed the results of that data. The main goal, just as in any learning situation, was continually and recursively drawn (Stripling, 1995) and aimed, not to deliver a final product or solution, but to formulate “ideas, understandings, and further questions” (p. 165).

The pre-experience investigations provided a base line from which to proceed. The participants’ espoused mental models on relevant concepts were compared and recorded. It is important for maximum credibility and reliability to use the results of early investigations to question the research tools’ validity and viability. The results could stimulate the need for other ideas or further questions (Stripling, 1995) to enhance the illumination of the in-action and reflective mental models of the next and subsequent stages of the journey.

The next stage posed some complex questions and challenges that were not anticipated at the commencement of the study. Bilbo Baggins encountered unforeseen hitches as he also strode forward on his journey and, just like Bilbo, vigilance and resourcefulness were needed to overcome the difficulties ahead.

CHAPTER FIVE: *In-Action Mental Models*

> Now it is a strange thing, but things that are good to have and days that are good to spend are soon told about, and not much to listen to; while things that are uncomfortable, palpitating, and even gruesome, may make a good tale, and take a deal of telling anyway. (Tolkien, 1937, p. 49)

Introduction

The research journey undertaken with the participants was not without discomfort. The design of any longitudinal study necessitates deep thought, predictions of likely success, and the implementation of purposeful problem-solving strategies that involve the continual activation of many mental models for the researcher. The real challenge arose when the anticipated responses from participants were not forthcoming through an implemented data collection method. The initial stimulated recall interviews with the students and teacher, as part of the investigation of the in-action mental models of the participants (Henderson & Tallman, 2006), were held two months into the project. However, strict adherence to the regular protocols for this data collection method failed to provide sufficient “there and then” (Henderson & Tallman, 2006) responses from the students to enable a satisfactory analysis of the in-action mental models they ran during the activity. After pattern coding the responses (Chapter 3), analysing the results and finding them deficient in quantity and quality, a decision was made to alter the stimulated recall interviewing protocol to facilitate collection of the required data while still maintaining the strict procedures of the methodology.

This chapter follows the pathway through the evolution of these resurrected protocols (Chapter 3) and also makes a “good tale” and “takes a deal of telling” (Tolkien, 1937, pg. 49). The journey began in May 2005 but the repercussions of events during the first and subsequent rounds of stimulated recall interviews would not be felt until later in the year. One of the student participants, Jim, left the school in September 2005. The substitute participant, Bree, had not participated in either of the stimulated recall episodes, although she had been included in the pre-experience semi-structured interviews. She would go on to participate in all data collection episodes from September 2005. Therefore, three of the four student participants and their teacher, Pamela, will be accompanied as they journey forward through the challenging interactions that occurred in the robotics experiences for the stimulated recall interviews.

The chapter validates the change to the protocol through literature review and improved data. It then discusses the data and the in-action mental models of four participants from the second round of stimulated recall interviews in three distinct sections. First, the opening minutes of each robotic lesson involved the students writing in their journals and this orientation to the lesson was videoed for inclusion in the stimulated recall interviews of all participants. Second, the body of the lesson itself was filmed and involved the students using problem-solving skills to construct and program the robots as Pamela moved around the room to support and observe. Third, the participants' mental models of the social constructive nature of their working environment were probed during the interviews and are discussed in the final section of the chapter.

Stimulated Recall Methodology

Stimulated recall methodology (Bloom, 1954; Ericsson & Simon, 1987; Gass & Mackey, 2000; Henderson & Tallman, 2006; Smagorinsky, 1994) is used as an introspective research technique to reveal cognitive processes, such as those exhibited by students in this study who were working with robotics. It is "messy" (Smagorinsky, 1994, p. x) work and, as Smagorinsky went on to state:

> no doubt the difficulty of replication, the idiosyncratic nature of each investigation, the need to reconceive hypotheses and data analysis procedures in mid-study, and other seeming indicators of imprecision have caused great consternation among those who find the methodologies 'unscientific' (p. x)

Nevertheless, stimulated recall has been used in many diverse fields including medicine where Saba et al., (2006) used the methodology as one of their "methodological lenses" (p. 59) to study the emic (Headland, Pike & Harris, 1990) perspective of patients during consultations with their physician. They found that a combination of the strictly-protocoled stimulated recall lens and the more circumspect observation lens enabled them to make useful recommendations regarding the often difficult communication that occurs between patients and doctors. The use of introspection information processing in combination with other data collection strategies (DiPardo, 1994; Henderson & Tallman, 2006; Jonassen, 1995; Saba et al., 2006) can enable realistic observation of cognitive processes in many interactions whether in medical consultation rooms or in the classroom. These observations can then be validated for accuracy and authenticity through triangulation (Burns, 2000).

Validity and reliability of an introspection methodology can be maximised through adherence to strict protocols (Ericsson & Simon, 1984; Gass & Mackey, 2000). The validity of the findings or the "accurate represent[ation] of the phenomena to which they refer" (Schwandt, 1997, p. 168) was promoted, in this study, by videoing and audio-recording the actual lesson and audio-recording the interview that also recorded the replay of the video-recording being played to the participant. Reliability and recall accuracy (Henderson & Tallman, 2006) were maximised by ensuring the 30 minute interviews were held within 24 hours after the events were recorded and by adhering to interview and coding protocols (Chapter 3).

An example of how this stimulated recall protocol was implemented and how subsequent analysis revealed the difference between "here and now" and the required "there and then" responses is illustrated in Table 5.1

Table 5.1: Segment of initial Stimulated Recall1 Interview with Pamela, 3 May 2005.

Source	Stimulated recall prompt and response
Video Replay	Pamela: Can someone add some more information to that? Student 1: You set a goal.
Paused:Pamela Pamela	*I'm trying to get the kids to build on each other's ideas* so I remember thinking**, all right, that's okay, but they can expand on that** so <u>I pass onto another student</u>, **they can build on the information there.**
Video Replay	Pamela: More information. Student 1: We say how we achieved a goal. Pamela: Does anyone want to add something else? Student 2: We read our journals to see if we achieved our goals. Pamela: Excellent.
Pause: Pamela Pamela	And the other thing is *that I'm trying not to add a value to what they say*. I know I remember thinking**, "Try not to be judgemental because at this stage we're just trying to get their ideas on paper. And if you're too judgemental you're guiding them."** *I don't want to guide them too much in my headspace. I want them to be able to put their own ideas down.*
Interviewer	So at the end of that [student's] journal comment . . .
Pamela	*I made a value judgement*.
Interviewer	You said you made a value judgement. So that's what you were thinking at the time, "I made a value judgement?"
Pamela	*No*. I was thinking**, "No, that's enough on that particular topic**." *Yeah, but looking back on the tape, I've made a value judgement.*

Note. All segments of the section of transcript have been included. The dotted line under the video section indicates a pause in the video replay that is followed by interviewer questions and/or participant responses during the stimulated recall interview.
Normal script = video transcript, questions by interviewer, and non-relevant responses by participant that linked the thoughts, descriptions, rationale, and explanations;
Bold script = **there and then thoughts and feelings**;
<u>Underlined script</u> = explanation of what participant <u>did during activity</u> or <u>actions</u>; and
Italicised script = here and now thoughts.

The participant provided a comment, “I made a value judgement”, as a conclusion to an open-ended prompt by the interviewer, “So at the end of that [student’s] journal comment . . .” (Table 5/1). The participant’s response is then repeated by the interviewer for clarification and then asks if this is what the participant was thinking at the time in order to explicate the category of the response given. The participant provides a negative response, that highlights the relevance of double checking. She removes any ambiguity by providing her precise thoughts at the time. Pamela supplements her “here and now” response that explains her perceptions of the actions and reactions at the time of the lesson with the thought, “No, that’s enough on that particular topic”.

This initial stimulated recall interview with Pamela, the teacher involved in the study, shows how the interviewer used non-directive questions and sentence starters to enable the interviewee to respond appropriately. The short transcript (Table 5.1) also illustrates the difference, as noted by the participant herself, between responses that were thought during the time of the activity or lesson and those that were thought during the interview.

However, sufficient data must be collected from all participants’ interviews to warrant a comparative analysis. Due to the “chimerical nature of inquiry” (Smagorinsky, 1994, p. x), there is often inadequate precedence to follow with a young cohort of students. The first round of stimulated recall sessions undertaken within this study failed to deliver sufficient data to enable the level of analysis of in-action mental models (Henderson & Tallman, 2006) that was anticipated. This lack of evidence was apparent through the “thoughts” or “feelings” offered by the student participants being either not of substantial quantity or their quality was viewed as being predominantly “here and now” responses. While the interviewer maintained non-directive questioning techniques and the interviews were conducted within twenty-four hours of the video-taped lesson (Bloom, 1954; Gass & Mackey, 2000;

Henderson & Tallman, 2006), the students responded mostly with, “I don’t know” or “I don’t remember”. These responses did not produce the required in-action mental models run during the learning experiences.

This lack of response may have occurred for various reasons, including the relatively young age of the student participants. This research is innovative because it fills significant and important gaps in longitudinal research of the mental models of primary/middle years students. While the lack of exposure to such interview techniques, and therefore possible contamination through rehearsal (Gass & Mackey, 2000) may be lessened due to the students’ first experience in such research, it also highlighted the need for the participants to have the cognitive maturity to understand the distinction between thoughts that happened during the lesson and those that were happening during the time of the interview.

While the students displayed positive attitudes during the stimulated recall interviews in May 2005, they often exhibited some frustration if they found themselves not recalling thoughts or feelings from the activity. Their numerous responses of “can’t remember” to pauses or prompts may have contributed to their sense of frustration with the interview. One of the participants, Ellen, clearly demonstrated her frustration when she stated, “*Still* no thoughts” after several prompts from the interviewer. The following section discusses the change to the protocol and provides evidence of the increased quality and quantity of responses due to this alteration.

Change of Protocol

An eight week interval eventuated between the two stimulated recall episodes, two weeks of which were the winter school vacation. The remaining six weeks covered a period where the researcher was involved in implementing new integrated units of work with her Year Six/Seven students; hence arrangements for the second stimulated recall sessions were delayed. The research students and teacher continued, through this time, their robotic activities and recording their experiences in their journals. However, the ineffective quantity and quality of the responses from the students were evident immediately after the initial Stimulated Recall interviews and these concerns were recorded by the researcher in her journal (Appendix O). What followed, in this intervening period, was the pursuit of a solution to this problem. Data were quantified and qualified again in the hope that there were enough thoughts to yield a satisfactory corroboration of the mental models being used during the activity. Such substantiation was simply not evident. Stimulated recall literature was trawled for comparable outcomes, without success, and there was much discussion between supervisor and researcher. A new question was added by the researcher to the interview script and another stimulated recall episode was organised with the teacher.

Quantity of Response

The change to the stimulated recall interview protocol included an additional opening question that enhanced students' recall yet maintained validity and reliability of data. The additional question, "What were you doing?", was asked when the video was paused by the researcher and encouraged the students to reconstruct events prior to answering the question, "What were you thinking/feeling then?" The use of this question, preceding the request for thoughts or feelings, was discovered in the literature when another search, sometime after the second stimulated recall episode, found a reference in the appendices of Marland et al.'s (1992) text. Other references to the use of the priori question were found in Hafner (1957) and Mayzner et al. (1964) who achieved increased responses when they asked their subjects to verbalize what they were doing before stating what they had been thinking.

The encouragement of students to verbalise the events and/or their actions in the lesson, as they watched the video replay of the event, strengthened the coincidental consciousness that was required to exteriorise the mental models. A segment of the stimulated recall interview held with Ellen in July 2005 (Table 5.2, next page) illustrates the protocol alteration where the additional question immediately after the pause in the video but *before* the priori question, "What were thinking then?".

Table 5.2: Segment of initial Stimulated Recall 2 Interview with Ellen, 15 July 2005.

Source	Response
Video Replay	Pamela: Wait for it to reboot. [Pamela stands up and moves back from Ellen and Jayne. She moves over to stand behind Sam who is working on his journal.]
Paused by Interviewer	

Interviewer	What was happening on the screen?
Ellen	<u>It was loading up and it kept on and when it got there</u> [to a certain point] <u>it was still frozen.</u>
Interviewer	Okay. So, what were you thinking when that was happening?
Ellen	**We would probably have to go to a different computer**

Note. All segments of the section of transcript have been included. The line under the video section indicates a pause in the video replay that is followed by interviewer questions and/or participant responses during the stimulated recall interview.
Normal script = video transcript, questions by interviewer, and non-relevant responses by participant that linked the thoughts, descriptions, rationale, and explanations;
Bold script = there and then thoughts and feelings;
<u>Underlined script</u> = explanation of what participant <u>did during activity</u> or <u>actions</u>.

Ellen was able to describe the actions of the computer, "It was loading up . . .", that provided recall of what she had been thinking at the time "That we would probably have to go to a different computer". The interviewer's response, "Okay", given after the description of the action confirmed Ellen's response. Even this level of affirmation to students' descriptions offers a validating experience that also encourages them to feel confident.

The useable responses of the students, Ellen, Jayne, and Sam, showed a marked improvement after the inclusion of the protocol change as shown in Figure 5.1. The results of this alteration in protocols (Figure 5.1) provided increases of 22% for Ellen, nine percent for Jayne, and a substantial 43% for Sam.

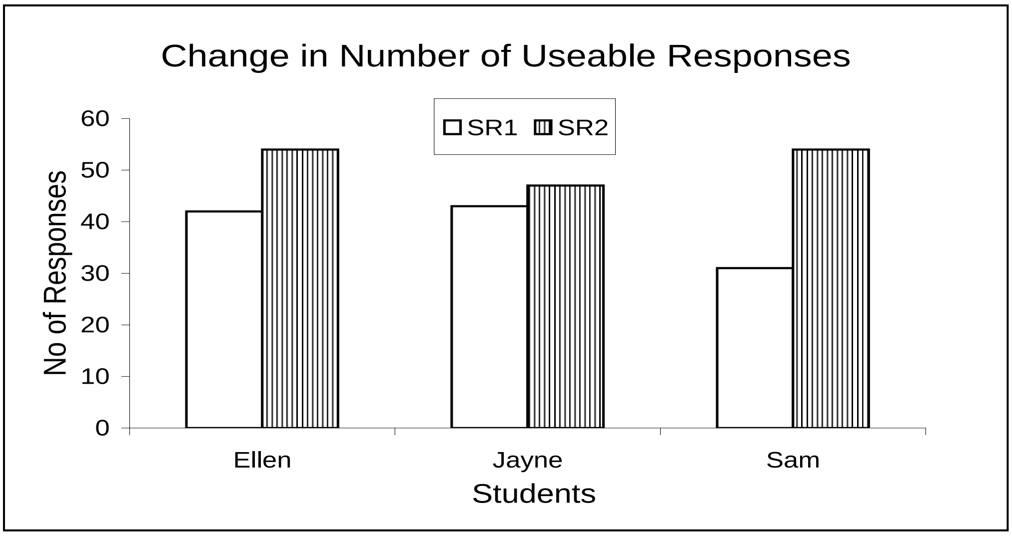

Figure 5.1 Change in number of useable responses from first Stimulated Recall episode (SR1) in May 2005 to the second Stimulated Recall episode (SR2) in July 2005.

The challenge of stimulated recall interview methodology is that retrospection asks a participant to recall thoughts associated with an activity that has occurred — not one that is occurring. The visual video prompt of the previous activity should have enabled participants to recall what they were thinking or feeling during a particular action or series of actions (Chapter 3). However, adding another prompt — such as the question, “What were you doing then?” — is adding a first step that personalizes the idiosyncrasy of self-observation (Cohen, 1998; Smagorinsky, 1994), thereby enhancing the strength of the association between action and thought. The priori protocol provided a double replay — on the screen and in their head — and enabled the students to return to the event and to replay the running of their in-action mental models before answering the question, “What were you thinking?”

The improvement in participant engagement was particularly evident from the reduction in “don’t remember” or “no thoughts” responses after the inclusion of the extra question in the second round of stimulated recall interviews (Figure 5.2).

While the useable responses were the key indicator that the protocol change had made a significant difference to the success of the stimulated recall interviews by enabling the participants to recall more in-action thoughts and mental models, the reduction in “no responses” is equally significant. Ellen’s “no thoughts”, reduced by a substantial 81%, indicates that she found the protocol change enhanced her recollection of thoughts and reduced her frustration at not being able to provide a suitable response to prompts by the interviewer.

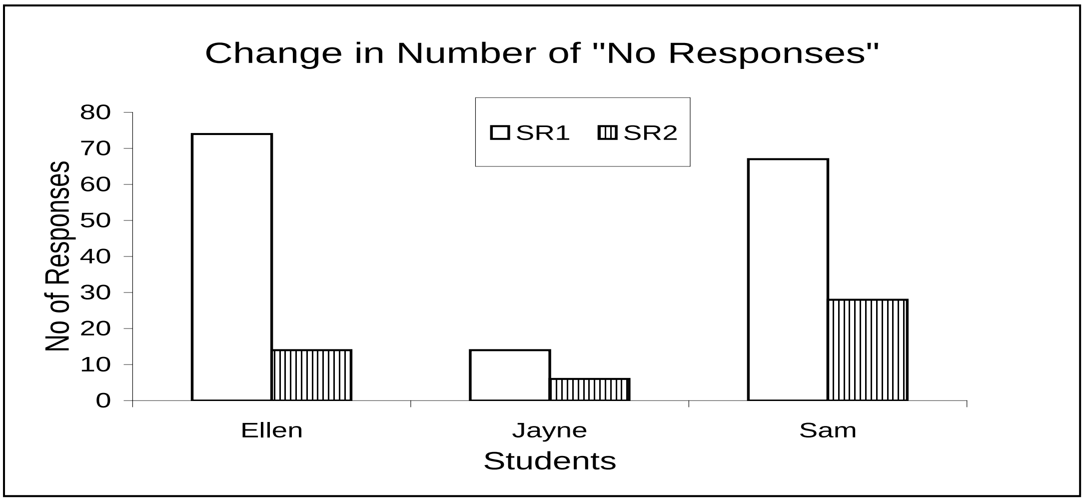

Figure 5.2 Decrease in “no responses” from the first Stimulated Recall episode (SR1) in May 2005 to the second Stimulated Recall episode (SR2) in July 2005.

Ellen's inability to respond with a recall of her thoughts reduced from 74 in the first stimulated recall interview to only 14 in the second! This reduction coincided with an increase in the useable in-action thoughts that she had at the time of the activity, from 42 to 54. Sam's 58% reduction in "no thoughts" from 67 in the first stimulated recall interview to 28 in the second coincided with an increase of useable responses from 31 to 54, is significant. The improvement in Jayne's responses as shown in Figures 5.1 and 5.2, while not as significant as those of Ellen and Sam, were also substantial with a 57% reduction in "no thoughts" from 14 in SR1 to six in SR2.

Ericsson and Simon (1984) proposed that an individual cannot store a memory in long-term memory unless it has been heeded or paid attention to when being run in short-term memory (Anderson et al., 1996; Power & Wykes, 1996). The opportunity for these students to re-run an action from the previous day that was linked to a thought increased their recall because of the "connected episodic memories and verbalization of their content" (Ericsson & Simon, 1984, p. 149).

The change in quantity was immediately obvious when the interviews were being conducted as the students were responding more fluently to probes. This response fluency to questions strongly suggests that participants would have increased confidence to engage efficaciously in any interview situation. An implication of the change of protocol and its outcomes to other types of interviews is significant and strongly suggests that enabling young participants to re-run their physical actions before providing thoughts enhances confidence and recall.

Quality of Response

The improvement in quality of response, while somewhat evidential during the stimulated recall interviews, became substantially apparent once analysis began when the richness of the students' responses contributed to a representational narrative of their in-action mental models. Crucially, there was a significant improvement in the quality of responses provided by the participants in the stimulated recall interviews that included the opening question, "What were you doing?"

This section of the chapter illustrates examples of the responses that one student gave in the two stimulated recall interviews as sample evidence of the improvement in response quality due to the additional question in the protocol. While all students exhibited this improvement, a section of Sam's interviews (Table 5.3) has been included to illustrate the evidence gathered by the researcher. It shows Sam responding to scenes on the video where, in both stimulated recall activities, he was experiencing some difficulty in programming the robot.

Table 5.3: Segments of Stimulated Recall Interviews with Sam, May and July 2005.

Stimulated Recall Episode 1 May 2005	Stimulated Recall Episode 2 July 2005
What were you thinking?	What were you thinking?
Yeah, I was reaching out to try and get the RCX.	**Umm. Just about finished.**
What were you thinking?	What were you doing?
I don't know! Just seeing if he was going to give it to me.	Oh. It hadn't beeped, so I had to go back through it.
What were you thinking?	What were you feeling while you were doing that?
Um. *I don't know*. Because I just, I pushed the wrong button so it would do its program again on the table.	**Annoyed still!**
What were you thinking?	What were you thinking while you were doing that?
Um. Um. I don't really know.	**Umm. Why isn't it receiving it?** *And then I'll [pause]* after that I thought**, "Well, I can't see anywhere where the infra-red is meant to be going to, so, maybe that bit is blocked there."**

Note. All segments of the section of interview transcript have been included. No video transcript is included.
Normal script = questions by interviewer;
Bold script = there and then thoughts and feelings of participant;
Underlined script = explanation of what participant did during activity or actions; and
Italicised script = here and now thoughts.

In the first stimulated recall interview segment in May 2005, Sam provided no recall of actual "there and then" thoughts although he was willing to describe what he was doing, such as "seeing if he [other student] was going to give it [the robot] to me". The thoughts attached to the action were not available to him. Sam may have had no particular reasons to attach any significance to the situation, shown in the video, because it had not been a problematic one for which an in-action mental model had been run and subsequently stored in long-term memory (Ericsson & Simon, 1984).

In the second stimulated recall interview segment, the additional question, "What were you doing?" was asked prior to the regular questions, and enabled Sam to reconstruct the episode that he had just viewed on the video screen before giving, what turned out to be, confident responses. Sam was able to relive the episode through the additional prompt that personalized his self-observation (Cohen, 1998). This recognition of the importance placed on his personalized or idiosyncratic response (Smagorinsky, 1994) enhanced the strength of the association of action, feelings and thought, and enabled him to provide the required detail. His thoughts indicate an in-action mental model that is attempting to provide an explanatory function as Sam considers alternative solutions to the problem (Johnson-Laird, 1983).

An example of Ellen's obvious improvement (Figure 5.2) is included in the appendices for further substantiation of this successful protocol alteration (Appendix X). An extract from Jayne's stimulated recall episodes is also included (Appendix X). Jayne maintained the most consistent level of responses across the two interviews, although there was some improvement in the second round of stimulated recall interviews (Figures 5.1 and 5.2). She rarely provided a "no thoughts" or "cannot remember" response to any pause in the video (Figure 5.2).

The students' reflections about their actions and the in-action mental models that they had run can also be linked with their individual level of metacognition or meta-ability (Anderson et al., 1996; Haycock & Fowler, 1996; Johnson-Laird et al., 1986) and their capacity to engage in quality thinking. What may be of interest to teachers and researchers, particularly in the field of learning and assessment, is the relationship between the ability to recall thoughts from an interaction in a domain, such as robotics, and a student's meta-ability. A student's capability to complete a task and their experience of thinking about their own thinking during such an activity may have some relation to their ability to confidently recall thoughts at a later date.

In-Action Mental Models

Journals

The students were required to write in their journals prior to commencing their robotic activities each week to encourage the establishment of individual goals for the lesson. Before writing this entry the students were instructed by Pamela to read the final entry from their previous activity that, if recorded correctly, should have outlined what they had achieved during that lesson. Each lesson entry had a specific code that was to be used and Pamela described it during the second stimulated recall interview as an aid that “helps me to know how many [robotic] lessons that they’ve actually had” because “if they number them and code them properly” they will “learn the numeric ways of organising information” (Pamela, Stimulated Recall Interview, 14 July 2005). Journal coding was seen, therefore, as an efficient method of recording the number of interactions the students had with the robotics equipment as well as their goals and achievements.

The journal also offered a means of communicating the students’ in-action mental models of their predictions of success, problem-solving capabilities, and, inadvertently, their sense of fun as shown in Sam’s journal for 5 May 2005 (Figure 5.3, coded 4A and 4B). Sam’s goal of “drag racing” remained consistent throughout 2005 and he continued to refer to this goal later in the year during the Focus Group Interviews (Chapter 7). Aside from this longer-term goal, Sam used his journal to record his achievements of completing certain missions as illustrated in the following journal entry (Figure 5.3).

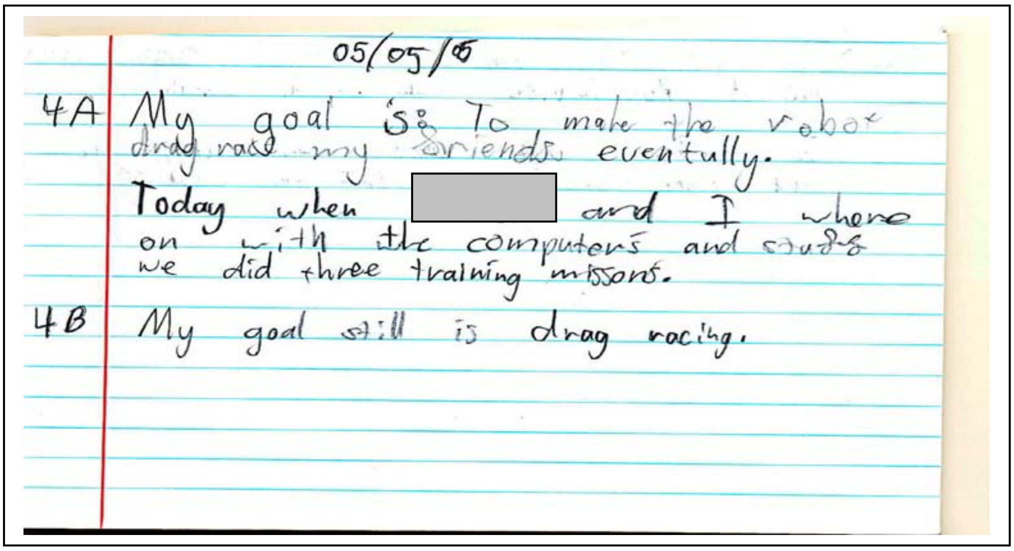

Figure 5.3 Sam’s journal entries[4] for the robotic lesson held on 5 May 2005.

Sam’s journal entry at the time of the second stimulated recall interview, coded 8A and 8B, showed that he was able to differentiate between the purpose of the entry at the beginning of the lesson and that of the one done at its conclusion (Figure 5.4) for the robotic lesson in July 2005.

[4] Sam’s partner’s name has been blocked out in both journal entries.

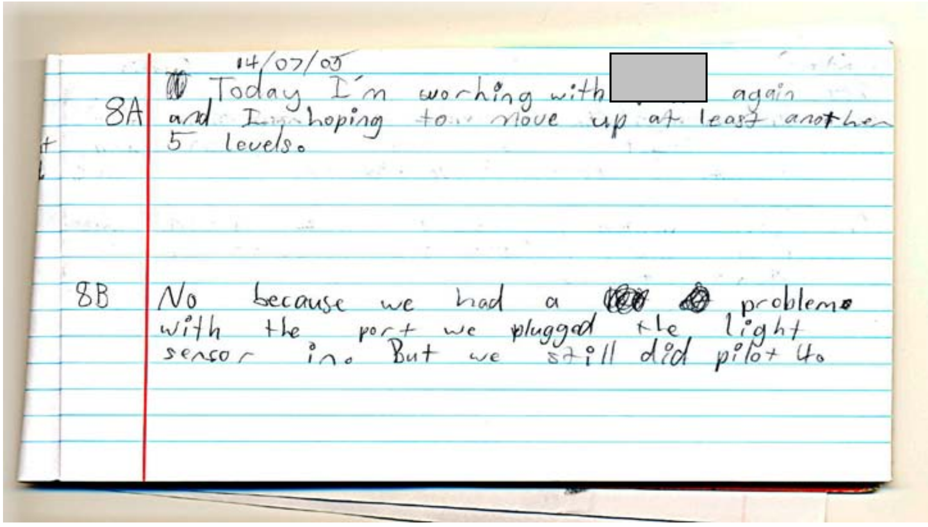

Figure 5.4 Sam's journal entries for the robotic lesson held on 14 July 2005.

Sam clearly states his goal to move up another five levels that may have been somewhat ambitious. His entry at the lesson's close, that explains the reasons for the problems that had been encountered in the activity, illustrates that this was the case and that he and his partner had managed to complete one pilot program. His recording of the actual problem that was encountered showed that the journal was being used quite effectively as a prediction for, and log of, experience.

Pamela's in-action mental model of the students' journal coding was clearly expressed in her stimulated recall interview (14 July 2005) as it "helps me know how many lessons that they've actually had". The opening frames of the robotics lesson, that was filmed for the stimulated recall interviews in July 2005, show Sam searching the pages of his journal while Ellen and Jayne started writing. Table 5.4 shows extracts from the stimulated recall interview with Pamela and with Sam when the video was paused at this particular point in both interviews.

Table 5.4: Pamela, Sam, and journal writing (14 July 2005).

Stimulated Recall 2: 14 July 2005	
Pamela	Sam
What were you thinking when you were looking through his [Sam's] book?	What were you doing?
That he hasn't understood that there's a sequence to the journal entries and that I had to reinforce that with him. That he really hasn't got that idea that we need to keep	I was trying to find the page. But I hadn't been in the robotics lab since my last entry and I hadn't been in it after that [pause] after the one yesterday as well. **So, I haven't achieved anything with that.**

track of exactly how many lessons you've had and where they're up to with those lessons. So we backtracked.	What were you thinking? **What am I gonna [sic] write.** *And that would've been to get up a couple of levels.* What were you feeling? **Hopeful!**

Note. All segments of the section of interview transcript have been included. No video transcript is included.
Normal script = questions by interviewer;
Bold script = **there and then thoughts and feelings**;
Underlined script = explanation of what participant did during activity or actions; and
Italicised script = here and now thoughts.

Sam's in-action mental model of using the coding for the journal entries is that of a novice compared with Pamela's expert mental model. Sam had not incorporated the mental model for coding into his general mental model of robotics because he was unable to find the correct page to use by following his coded entries. The incorporation or assimilation of that specific knowledge had not occurred because the phenomenon of coding and how a student relates to it (Johnson-Laird, 1983), and its relevance to tracking progress through the program, may not have been made clear to him. Subsequent instruction in lessons, where the code was used, failed to stimulate the running of the mental model required for it to become functional.

The diagnostic function of Pamela's in-action mental model mismatched the in-action mental model of Sam who, while having difficulty in finding the correct page, was concentrating on what he was going to write as his goal for that lesson. Pamela was controlling her in-action mental model by demonstrating an understanding that Sam needed more scaffolding in order to assimilate the coding concept into his in-action mental model (Table 5.4). Pamela's in-action mental model of coding was guiding her use of teaching skills (Norman, 1983).

This mismatch illustrates the individualisation of mental models (Jonassen, 1995; Norman, 1983) and how what may be workable for one is not for another (Greca & Moreira, 2000). Sam's in-action mental model of robotics was working quite effectively for him without containing the specific mental model of coding that his teacher required of him. Therefore, while a mismatch does exist in this area, what might be analysed by the teacher is the timing of the imposition of a mental model such as the one for "coding the journal", when so much else is being newly experienced. It is valid to challenge the appropriateness of the timing of such knowledge when it appears that this, and perhaps other, students' existing mental models may be guiding them through a satisfactory engagement with the activities. Sam's "there and then" thoughts had been about what he was going to write without knowing the specific goal at that time. His "here and now" thoughts explained that the content of his goal would have been to "get up a couple of levels". His feeling at the time was one of "hope" so he had been making a link between the affective domain and the cognitive domain associated with predictions of possible successes.

Both Ellen and Jayne appeared to have less difficulty with journal writing. Their comparative responses to prompts coinciding with the pause in the video are illustrated in Table 5.5 below. Both Ellen and Jayne were able to provide thoughts that indicated their in-action mental models of journal writing were functional because they integrated the concept of how the code should be used and what detail they were to incorporate.

Table 5.5: Ellen and Jayne and journal writing (15 July 2005).

Ellen	Jayne
What were you doing?	What were you doing?
To get up to the next training mission. *And sometimes I write, like, certain things that I want to know what to do.*	I tried to write quickly so I wouldn't forget what I was going to write.
What were you thinking?	What were you thinking?
Let's see if we can make it up to the next training mission. *How I will write it down in the sentence.*	**I thought this would be quite easy because I always know what to write in it … the things that I did achieve and what I didn't,** *so I'll know what to write for the next one* **… what missions I could do and if it was easy.**

Note. All segments of the section of interview transcript have been included. No video transcript is included.
Normal script = questions by interviewer;
Bold script = **there and then thoughts and feelings**;
Underlined script = explanation of what participant did during activity or actions; and
Italicised script = here and now thoughts.

Ellen's in-action mental model displayed the communication function by the inclusion of the need to "write it down in a sentence" that indicates it also included the need for syntactical and semantic accuracy. Jayne's transcript illustrates mental model's memory mechanism through her clear understanding of the need to include what she did and did not achieve because this would assist her in remembering “what missions I could do and if it was easy”.

This journal was a valuable organisational tool that enabled the students to improve the effectiveness of their working memory by, firstly, providing an aide memoire to record their thoughts, progress, and failures and, secondly, by creating an opportunity to run their in-action mental models of robotics in working memory (Anderson et al., 1996; Johnson-Laird et al., 1986). It promoted the running of predictive mental models (Johnson-Laird, 2006; Vosniadou, 2002) when they recorded their goals for the lesson. Those mental models then could be adapted or refined when the students recorded their achievements at the end of the lesson. Subsequent predictions in following lessons would reflect mental models of the previous experiences.

The journal enabled a more rapid retrieval of the required mental models (Rouse & Morris, 1986). When students entered the robotics laboratory to continue their activities the previous journal entries triggered the predictive functionality (Bibby, 1992) for this lesson. Mental models that were run (Johnson-Laird et al., 1986; Norman, 1983; Payne, 1992) in order to find the appropriate successful solution to the construction and programming requirements of the task in previous lessons were retrieved for guidance with new predictions. Sam and Jayne’s journals were clearly providing a record of success and failure and therefore created a guide to future activity. This was one of the purposes that Pamela had envisioned.

Problem-Solving

The students encountered problem situations in July 2005 when they were constructing their robots and programming the computer to give instructions. By this time, although the students had had eight or so sessions in the robotics laboratory, they were still working through the training missions that were designed to introduce students to the basic functions of the sensors available for the robots and the basic programming operations they would use to operate them. The training missions entailed selecting a pre-established pilot program, clicking on the available icons to construct a sequence, and downloading it to the robot. The robot itself required construction to specifications that were outlined in the constructopedia that accompanied the kit. Each program in the training missions introduced the students to a different sensor that was available to program the robot to undertake a task.

Sensors enabled the robot to “see” light and shade and to “touch” objects and move away from them by using light and touch sensors.

The following interview extracts confirm the in-action mental models of the participants as they encountered problems with the robotic hardware. The video shown to the students, before the pause that instantiated the responses in the transcript in Table 5.6, had depicted their actions of collecting the robot, looking at it closely, and then sitting down at the computer.

Table 5.6: Ellen and Jayne predicting outcomes (15 July 2005)

Ellen	Jayne
What were you doing?	What were you doing?
To look [sic] at the computer, to see if the robot on the computer was [pause] looked the same as the one that we had.	Going through the steps. To see if it would work. Seeing it they were the same and if we needed to put anything on it or take anything away.
Ellen	Jayne
What were you thinking?	What were you thinking?
Like, still **hoping that it was.**	**It’s quite complicated because it kept showing us stuff that we didn’t have** so we just took if off and built it again.
What were you feeling?	
Oh. We have to build it again!	

Note. All segments of the section of interview transcript have been included. No video transcript is included.
Normal script = questions by interviewer;
Bold script = **there and then thoughts and feelings**;
Underlined script = explanation of what participant did during activity or actions; and
Italicised script = here and now thoughts.

This transcript highlights the difficulty that the students experienced, at times, in expressing their feelings about their interactions with the domain. Ellen’s response to the prompt, “What were you feeling?” was, in fact, a there and then “thought” about having to rebuild the robot. This response might also indicate that she believed what she “thought” at the time was more important than how she “felt”. Both Ellen and Jayne were running in-action mental models that contained an understanding of the procedural knowledge required to correctly build, and subsequently program, the robot. Their in-action mental models were performing the predictive function as they were attempting to forecast the outcome of various scenarios (Bibby, 1992). This simultaneous activation of several, or parts of several, in-action mental models (Holyoak, 1991) uncovered the need to do some alterations to the construction of the robot by removing the touch sensor and replacing it with the light sensor.

The interactions in the next table, Table 5.7, indicate that the students had been operating with different in-action mental models of the procedures required to construct and program the robot. This difference in mental models highlights the lack of homogeneity that can exist in a pair or group despite the appearance of synchronicity within the working relationship.

Table 5.7: Ellen and Jayne problem-solving with sensors (15 July 2005).

Ellen	Jayne
What were you doing?	What were you doing?
Well, we were getting a different robot to see if there was another different one that didn't have the touch sensor on. *The boys had it.*	We went into the cupboard to get the instruction manual for the robotics so we could build the other bit.
What were you thinking?	What were you thinking?
Yeah, well, I felt that [pause] like that … I'm not very good at building.	**I thought it would be pretty easy because I know where they are.**
What were you doing?	What were you thinking about the construction?
If the touch function was on we had to take it off.	**I thought it would be quite hard because it's quite hard to build those little things, like putting them on and stuff.** *It's just something I don't understand.*
What were you thinking?	What were you thinking?
That we had to get a different sensor. *I think we had a robot, but it had a touch sensor on it.*	**It felt good** *because I knew it needed a little bit of work.* **I just thought, "Isn't it fun? Just take it off and see what we needed to replace it with."**

Note. All segments of the section of interview transcript have been included. No video transcript is included.
Normal script = questions by interviewer;
Bold script = there and then thoughts and feelings;

Underlined script = explanation of what participant did during activity or actions; and *Italicised script = here and now thoughts*.

Their mental models were controlling their actions of explaining what was happening (Norman, 1983), illustrated by Ellen's explanation of her action in seeking a robot that did not have the touch sensor. The mental models she had while looking for the robot incorporated a belief that she was not proficient at building and held a possible solution. She understood that students who worked in the robotics laboratory before her often left a constructed robot in the cupboard. This pre-built robot would make their progress more assured. Jayne's in-action mental model includes the knowledge that finding an instruction manual is easy, building the robot is hard, although it would require just a "little bit of work" to replace the sensor.

The students were sharing a reality, but their mental models contained different explanations of the difficulties associated with replacing the sensor. The social negotiation of the shared activity involved semiotic mediation, a process where psychological tools, such as questioning and acceptance (John-Steiner & Meehan, 2000; Smagorinsky, 1995), are used to socially construct knowledge. This social construction of a shared reality obviously does not necessitate the activation of the same or similar mental models; only that each participant in the mediation be able to exteriorise and communicate the mental models they are running in a meaningful way.

While the students continued to struggle with the building of the robot, that later required a refit with different parts and a sensor, it became apparent that there was a mismatch in their in-action mental models about the procedural knowledge required to construct the robot (Table 5.8).

Table 5.8: Ellen and Jayne refit the robot (15 July 2005).

Ellen	Jayne
What were you doing? I was trying, like, to put it together like the book was doing it. And Jayne was just trying to put the sensor just on the robot.	What were you doing? Building the rest of the bits that we needed to put on the robot. It wouldn't go on.
What were you thinking? **Oh, we need to do this . . . she needs to look at the book next time she tries to build.**	What were you thinking? **I just thought that it was a bit silly because I put them on and it didn't work, so . . . I don't know what to think!**

Note. All segments of the section of interview transcript have been included. No video transcript is included.
Normal script = questions by interviewer;
Bold script = **there and then thoughts and feelings**;
<u>Underlined script</u> = explanation of what participant <u>did during activity</u> or <u>action</u>; and
Italicised script = here and now thoughts.

Ellen's in-action mental model for the procedure of building the robot includes referring to the constructopedia that accompanied the Lego™ Dacta equipment, or "book" as she refers to it in her recall of thoughts at the time. Her in-action mental model of robotics is guiding her to search for constructive assistance. This controlling function of mental models (Henderson & Tallman, 2006; Newton, 1996) is guiding her use of the resources available thereby enabling her to use them to affect a solution to the construction problem.

Jayne's in-action mental model of constructing a robot included the thought that "it", or the problem they were having with construction, was "silly" and that she expected it to work when she put the sensor on the robot. She verbalised her confusion when the solution was not as easy as she expected by expressing the thought, "I don't know what to think". Jayne's in-action mental model was not sufficient to provide an explanatory function of the problem. She was unable to run a mental model to look for counter examples (Johnson-Laird, 1983) or to consider available resources to help solve the problem.

This mismatch in the explanatory and predictive functionality between the students' in-action mental models continued throughout the rest of the lesson. Some time after this, Pamela suggested that they try to reprogram the robot. Ellen's response to this prompt was to exteriorise her in-action mental model by stating her thought at the time, "We don't really need to try again because we had already built it wrong". In other words, until the robot had been rebuilt correctly, their attempts at reprogramming the computer were going to be pointless. Jayne's in-action mental model of the problem with the robot matched Ellen's at this point with her recollection of her thoughts including, "I already knew what was wrong with it because it was built wrong" after she compared it to the picture on the screen. The controlling functionality of Jayne's in-action mental model, however, did not match Ellen's at this point as they were being guided by two distinctly different mental models as they searched for a solution: Ellen's mental model of consulting the book and Jayne's lack of a clear mental model of problem-solving. Semiotic mediation (John-Steiner & Meehan, 2000) was occurring through the two tools of language, English and the computer programming code (Smagorinsky, 1995). However, although this sharing was enabling both students to externalise their understanding of the situation, it did not culminate in the successful completion of the activity.

Sam and his partner encountered construction and programming problems during the second stimulated recall session and their first attempt at programming resulted in the robot spinning in a circle. Appendix Y is a transcript of the interactions that occurred between Pamela, Sam, and his partner prior to the pause in the video that preceded the prompts for the interview segment illustrated in Table 5.9. The video transcript (Appendix Y) provides a fuller picture of what the interview participants, Pamela and Sam, had viewed before the video was paused and the questions asked by the interviewer. It reveals Pamela stepping the two students through the actions that they need to undertake to prepare the robot for this particular program. She observed the students completing the programming correctly and questioned them about the placement of the robot on the activity pad. This probing helped Pamela to establish whether or not the students have constructed and programmed the robot correctly.

Table 5.9: Pamela and Sam observe Sam's robot in a spin (14 July 2005).

Pamela	Sam
What were you thinking? **I'm quite amused by the fact that it didn't actually do** [pause] **I've a fair idea that it wasn't going to because there is actually a glitch in this particular design that I have come across with some of the other kids. But I still have to let them find that out themselves.**	What were you doing? <u>The robot was spinning round clockwise, but it wasn't doing what it was supposed to!</u> What were you thinking? *I was thinking*, **"Why isn't it doing what it was supposed to do?" I kind of felt that was a bit annoying.**

Note. All segments of the section of interview transcript have been included. No video transcript is included.
Normal script = questions by interviewer;
Bold script = **there and then thoughts and feelings**;
<u>Underlined script</u> = explanation of what participant <u>did during activity</u> or <u>action</u>; and
Italicised script = here and now thoughts.

The transcript of the interviews in Table 5.9 shows the thoughts that Pamela and Sam recalled from this interaction that concluded with the robot turning in a circle rather than (a) moving to the dark line, (b) sensing the dark colour of the line, and (c) turning away to the left for one second. The video was paused at the same place in both interviews to allow the interviewer to gain an understanding of the in-action mental models both participants were running at the time.

Sam was asked what he was doing while sitting at the computer when his partner had pressed the button to operate the programmed robot. His response provided a description of what the robot was doing, rather than what he was doing, that is credible because what he had just observed on the screen was of greater importance to him than what he might have been doing at the time (watching it incredulously!). However, there had been a great deal of interaction between the three students leading up to the point when the robot was activated. Sam's response to the next question, "What were you thinking?", demonstrated that he was experiencing some perturbation at the events that were unfolding. His thought about why the robot was not working as it should (Table 5.9) signalled that his mental model of robot programming was probably running a diagnostic function. Sam was being confronted with a contradiction that he could not assimilate into his mental model (Stripling, 1995). Then he was in the process, with Pamela's guidance, of restructuring that mental model (Barker, van Schaik, Hudson, et al., 1998) in order to solve the problem. His memory of feeling annoyed confirmed his disequilibrium (Piaget, 1970) that the construction and programming of the robot had not gone as smoothly as he had predicted.

Meanwhile, Pamela was running mental models that enabled her to scaffold progress through the problem situation. Her response to the question, "What were you thinking?", revealed confirmation of her mental model of teaching and learning: a social constructivist pedagogical mental model that guided her interaction with the students during critical problem-solving situations. Pamela indicated her awareness, that the students were operating with mental models that would not allow them to assimilate the information required to solve the problem (Royer et al., 1993) on their own, by her comment that she had "to let them find that out themselves". In this instance, Pamela was instantiating the process-outcome prediction function (Kyllonen & Shute, 1989) for assessing mental models of students, as she was providing opportunities for the students to attempt to solve the problem prior to advising them of a particular "glitch" (Appendix Z) that existed in the design of the robot for that program. This was a valuable teaching/learning moment that, while "annoying" for Sam, would prove beneficial in the long-term because it enabled him (and other students) to have many opportunities to run mental models (Barker, van Schaik, Hudson, et al., 1998) in challenging situations to strengthen functionality.

The difference between the running of expert and novice mental models by the participants can be demonstrated by the approach to the ‘glitch’ in the program. As the students stumbled to find their way past it, Pamela recalled thinking, “It’s probably time to guide them a little more”, thus signifying her understanding that their inexperience with the program, and its idiosyncrasies, was hindering their quest for a valid solution. She was operating with an expert mental model of the program. Sam, who was operating with a novice mental model of the program, admitted during a subsequent pause in the video that he remembered thinking, “I need to listen to the instructions”, indicating that he had, in the past, deliberately missed teacher explanations. In this instance, he might have believed that Pamela had already explained the glitch at some point but that he had not been listening at the appropriate time.

Pamela used her expert mental models to act as the guide on the side (Vygotsky, 1978) to point Sam and his partner in the direction of the “information” section of the computer program. Sam recalled thinking, “I hate going into things that I didn’t think I need” and the reality of using this help line was something he thought he “didn’t want to do”. This reflection is evidence of Sam’s novice mental models in robotics because he held mistaken beliefs (Leviton, 2003) that he did not need the assistance that could be provided by the information section of the program. The consequence of this novice mental model was an inability to find a solution. Sam was also skimming over the complexity of the problem (Williamson, 1999) due to both his limited experience and his erroneous mental models that past experience at solving technical problems in other areas would transfer easily to this situation.

The subjective explanatory value of Sam’s in-action mental model (Seel & Strittmatter, 1989) indicates how difficult he felt it was to abandon his inaccurate or incorrect in-action mental model (Norman, 1983). Sam’s parsimonious (Norman, 1983) in-action mental model led him to reject the use of the information section of the program. This rejection of a possible avenue of assistance was, in all likelihood, due to the evolution (Mayer, 1989; Norman, 1983; Williamson, 1999) of his mental model that negated the usefulness of this information section. Sam’s rejection of a possible source of help occurred even though this negation was proving inconsistent with his ability to find a solution to the problem.

The glitch in the program continued to plague the students, including Sam. He believed he had solved the problem with the construction and programming. However, his robot still could not receive the downloaded program through the infra-red. Sam had carefully reviewed the program and checked the construction of the robot and found that, after manipulating the infra-red, it was functioning but "it was the robot that had the problem". He admitted thinking "that we had moved a little step further in solving it" because of this discovery.

Simultaneously, Pamela was thinking, "I'm not going to spoon feed them. We'll just take them through. I need them to think about, 'Okay, what's wrong?' and that's all part of problem-solving" (Pamela, Stimulated Recall Interview, 14 July 2005). Here, Pamela was relying on the diagnostic function of her in-action mental model to enable her to understand that Sam was working with in-action mental models that did not allow him to assimilate the new concepts (Royer, et al., 1993) required to solve the problem. Pamela wanted Sam to realise that the design flaw of the robot's sensor attachment was hindering the receipt of the program from the infra-red.

Ten minutes later, Pamela was still trying to guide the students, including Sam and his partner, to the source of the problem. The program could not download while the sensor was in place, so it needed to be removed prior to the download process. The construction was correct. The program was correct. In this case, Pamela's motives for not disclosing the consequence of this design flaw can be challenged. The students, through their lack of experience with the robotics program, had little conceptual understanding of the complexities of the systems and, therefore, could not have used their in-action mental models to predict, explain or even diagnose such a problem.

The final section of transcript below in Table 5.10 shows the recalled thoughts and actions of Pamela and Sam as the programming completes successfully.

Table 5.10: Pamela and Sam troubleshoot through the problem (14 July 2005).

Pamela	Sam
Video replay: Pamela shows the students the "information" section on the computer program	
Paused: Interviewer	
What were you thinking? **Yep! Show them a secondary source of information which they hadn't seen before.**	What were you doing? <u>Ahh. I'm looking at the ones of which [sic] to select to give you the information</u>

They had not used it before? *No, they weren't familiar with that at all. That was the first time they'd seen it.*	What were you thinking? **Hopefulling [sic] it will work.**

Pamela	Sam
Video replay: The RCX moves correctly.	
Paused: Interviewer	
What were you thinking? **Good! Yeah, I felt good. They'd solved a problem.**	What were you thinking? **It worked . . . relieved because it finally worked and we didn't have to**

Pamela	Sam
	do anything else. *Because I don't know what we would have done.*
Video replay: Pamela reviews troubleshooting steps.	
Paused: Interviewer	
What were you thinking? *I was quite satisfied with the progress that they'd made* and **thought, "Alright, that's enough for one day, enough for them to absorb."** *Because they both seemed fairly satisfied with the fact that they'd got it going and that they'd done a fair bit of thinking, too, and a fair bit of work.* **It's important to get them to write in their journals straight away, while it's fresh in their memory**.	What were you thinking? **Like I was in trouble. Sort of.**
Video replay: The boys start to experiment with the RCX by placing it in different places so that the light sensor would pick up different colours.	
Paused: Interviewer	
What were they doing? Well, they were taking it one step further. What were you thinking? **Alright then, okay, let's see if we can actually get this outside the constraints that we've been given. That's quite good scientific experimentation.**	What were you doing? I moved it forward so it would turn into the shadows. What were you thinking? **It might have stopped because it was darker.** *But it stopped because it hit the table leg.*

Note. All segments of the section of transcript have been included. The line under the video section indicates a pause in the video replay that is followed by interviewer questions and/or participant responses during the stimulated recall interview.
Normal script = questions by interviewer;
Bold script = **there and then thoughts**;
<u>Underlined script</u> = explanation of what participant <u>did during activity</u> or <u>action</u>; and
Italicised script = here and now thoughts.

The transcript shows clearly how stimulated recall interviews can illuminate the mental models of different participants in the same activity. Pamela was guiding the students through a frustrating problem-solving situation without “spoon feeding” them the answer. This process, while enabling the students to locate solutions themselves, also challenges in ways that are linked to the affective domain, such as the personality of the child. Continued frustration at failure can be detrimental to the pursuit of a solution and, when the expected assistance does not arrive from a knowledgeable source, then students may give in to the frustration and discontinue their search altogether. Here, Sam did continue his search for a solution as his in-action mental model of robotics allowed him to interpret, remember, and communicate the outcomes (Wild, 1996) he was getting from his tested solutions. He even pursued further experiments following the successful programming (Table 5.10).

Pamela’s mental model of her students demonstrated a good understanding of how far they, including Sam, could be encouraged to find answers on their own before she needed to provide detailed assistance. She took the students a little beyond that with which they were comfortable (Vygotsky, 1978) in order to create an authentic learning situation for which they were required to activate a variety of in-action mental models that involved their explanatory and predictive functions. Here, Sam was required to have a “working model” of the situation in his mind (Johnson-Laird, 1983) in order to be able to test possible scenarios (Carley & Palmquist, 1992; Renk et al., 1994) to find the appropriate solution.

Social Construction

This section illustrates the interactions between two participants, Ellen and Jayne, during the second stimulated recall episode on 15 July 2005. While being in the same class, the four students anonymously selected for the in-depth data collection episodes, were not socially interactive and shared different friendship groups. What was of interest was whether the stress of encountering problems with either construction or programming would impact on their ability to work effectively with each other. What psychological tools (John-Steiner & Meehan, 2000; Smagorinksy, 1995) would they use to find a way forward together? What in-action mental models of social negotiation would they use to engender, not just a peaceful coexistence, but a fruitful one?

Just as Bilbo and the dwarves needed to find the right balance between individuality and acceptance of each other, these children would need to run in-action mental models that enabled problem-solving to take place while working together. The stress of finding a solution to the difficulties they encountered in programming and construction did have an effect on Ellen's and Jayne's partnership. Ellen moved to the computer, usually Jayne's role, to trouble-shoot the program when Jayne moved to the cupboard to find some pieces for the robot. Table 5.11 shows their individual interview responses to prompts when the video replay was paused at the time when Jayne returned to the computer where Ellen was sitting.

Table 5.11: Ellen and Jayne at the computer (15 July 2005).

Ellen	Jayne
Video replay: Ellen is sitting at the computer to program the robot. Jayne returns and stands beside Ellen. Jayne starts pointing to the screen as Ellen clicks on icons in the program.	
Paused: Interviewer	
What were you doing?	What were you doing?
She was like, showing me where to click and everything.	I kept pointing to the screen because she kept waiting for ages before clicking on it and I just usually like click and like click it as soon as it says it.
What were you thinking?	What were you thinking?
She didn't really need to do that, because there's a running arrow pointing to there in the computer.	**She's a bit slow. She shouldn't do that.**

Note. All segments of the section of transcript have been included. The line under the video section indicates a pause in the video replay that is followed by interviewer questions and/or participant responses during the stimulated recall interview.
Normal script = questions by interviewer;
Bold script = **there and then thoughts and feelings**;
Underlined script = explanation of what participant did during activity or action; and
Italicised script = here and now thoughts.

The students had been unable to solve a problem with the robotic activity. The transcript illustrates the idiosyncratic communication function (Norman, 1983) of mental models as Jayne points to the screen to instruct Ellen on the correct path through the robotics program (Table 5.11). The students were certainly not sharing a transitory mental model (Anderson et al., 1996). Nor were they undertaking any effective collaborative critiquing (Henderson & Tallman, 2006) to assess how they would proceed effectively to a solution. Jayne's mental model of Ellen was that her progress was "a bit slow" and her ability possibly incompetent, while Ellen's mental model depicted Jayne's actions as excessive. Their inability to use their mental models to communicate effectively, at this point, hindered their ability to move forward.

However, as they continued to work alongside each other they ran mental models that included psychological tools and social cues (John-Steiner & Meehan, 2000; Smagorinksy, 1995). The video transcripts of the next part of the robotics activity are shown in Table 5.12 and illustrate how Ellen and Jayne used their mental models to find a way forward past their difficulty in communicating.

Table 5.12: Ellen and Jayne work together to program (15 July 2005).

Ellen	Jayne
Video replay: Jayne: Press that. Jayne points to the bottom of the screen speaking to Ellen. The Program voice states: "This completes step one." Ellen continues on to step two and clicks the mouse to alter the program before the program voice gives the full instructions. Jayne points to the screen a couple of times during these instructions.	
Paused: Interviewer	
What were you feeling? **I felt Okay.**	
What were you doing?	What were you doing?
It [the computer arrow] was like, already pointing to it, so I already clicked on it.	She went faster. She's doing it fast, which is good.
What were you feeling? **I felt ease** [pause] *it felt easier***.**	
What were you doing? She kept pointing.	

Video replay:
Jayne puts her finger on the mouse and clicks it. Ellen continues looking at the screen and puts her hand back on the mouse. When the program voice asks to backspace on the keyboard, Jayne leans over and presses that key on the keyboard.
Ellen continues using the mouse.

Paused: Interviewer	
What were you thinking?	What were you thinking?
It was funny.	**I felt, that's good because we'll probably get it done in time.**

Note. All segments of the section of transcript have been included. The line under the video section indicates a pause in the video replay that is followed by interviewer questions and/or participant responses during the stimulated recall interview.
Normal script = questions by interviewer;
Bold script = there and then thoughts and feelings;
Underlined script = explanation of what participant did during activity or action; and
Italicised script = here and now thoughts.

Ellen did not take offence when Jayne persisted in pointing to the screen. Jayne's actions seemed to satisfy her need to contribute to the efficacy of the programming. There are various social cues that individuals employ as they collaborate to share mental models (Breazeal, 2002) including directing action, as illustrated by Jayne, and participating in turn-taking, as shown by Ellen when she shared the keyboard and mouse with Jayne (Table 5.12). Both students now appeared to understand the non-verbal feedback they were receiving from the other and, this particular psychological tool (John-Steiner & Meehan, 2000; Smagorinsky, 1995) enabled their distributed mental model of communicating to assist them through this cognitive and social problem situation.

The students also found it necessary to actively negotiate solutions to their socially deconstructive moments. One such moment of negotiation was when Ellen and Jayne returned from their visit to the cupboard that stored the robotic equipment, to collect the constructopedia that would, they hope, guide them to correct any construction errors on the robot. Ellen had already been seated at the computer for a short period (Table 5.12) that was a role that Jayne most commonly took. However, a level of frustration with the building of the robot had crept into the activity because both of the students realised that it was built incorrectly when the program they had designed would not download. When they both returned to their station, Ellen sat at the computer again. The following transcript in Table 5.13 shows what happened next and their responses to pauses in the video replay of the events.

Table 5.13: Ellen and Jayne share the computer (15 July 2005).

Ellen	Jayne
Video replay: Both girls return to their station after retrieving the constructopedia from the cupboard.	
Paused: Interviewer	
What were you doing? I think I did it automatically - sat down at the chair because I'm probably just used to sitting at the front of the computer. *So I could have a turn.*	What were you doing? I don't know. Because I was looking at the thing [robot] there.
What were you thinking? **Glad that I just didn't have to sit down and watch!**	What were you thinking? **I thought, "It must be her turn. She must want a go." I thought it was fair. It was alright!**

Note. All segments of the section of transcript have been included. The line under the video section indicates a pause in the video replay that is followed by interviewer questions and/or participant responses during the stimulated recall interview.
Normal script = questions by interviewer;
Bold script = **there and then thoughts and feelings**;
Underlined script = explanation of what participant did during activity or action; and
Italicised script = here and now thoughts.

Jayne offered her thoughts that it was "alright" for Ellen to sit at the computer at this point while she looked at the "thing" [the robot] that was beside the computer. However she did not spend much time looking at the robot as the video showed she stayed next to Ellen for only a moment before moving off toward the cupboard again. When asked what she was doing, she responded, "I think I was going to get the book because we built it wrong. She [Ellen] looked at the picture and it was wrong". The evidence in the video replay clearly indicated that both girls had just returned from the cupboard after retrieving the constructopedia book so Jayne's decision to move from the station was not for this purpose. Jayne exhibited reticence to undertake any responsibility in the construction of the robot. This aversion to building the robot was confirmed in the post-interview segment (Chapter 5) when Jayne offered the opinion that building the robot was her least favourite part of the robotics activity. Jayne expressed her unwillingness to persist with the trouble-shooting of the robot construction problem by stating, "we just gave it one more shot then gave up . . . our confidence went down". The robot did not resemble the one on the screen or in the book and she gave up trying to address the discrepancy.

While both girls exhibited novice mental models because their knowledge of problem-solving strategies were soon exhausted (Leviton, 2003), Ellen appeared to be exhibiting the recursivity (Power & Wykes; 1996) of mental models as she returned to the construction of the robot, after Jayne had stopped, in an effort to find and fix the error. Ellen had sat at the computer (Table 5.13) only long enough to have her "turn" at reconstructing the computer program before realising that the error was not there. Ellen was attempting to problem-solve in a novel environment while running in-action mental models that were suggesting new avenues for the solution to the problem. These new strategies would be incorporated in the mental model (Henderson & Tallman, 2006) as Ellen worked on the process of reconstructing the robot by looking at the constructopedia and the computer screen. While she was working through this problem-solving situation she would have been running mental models for both the plan of what she was to do and the action of how to accomplish the action itself (Cohen et al., 1995). When questioned during the post-interview segment, Ellen explained her action of returning to the robot after sitting at the computer was because she was ". . . trying to make it work . . . so we could achieve our goal".

At the end of the activity Pamela confirmed what both of the students had realised that, unlike the situation with the two boys, the computer program was not the problem. The construction of the robot had been incorrect. Ellen's mental models demonstrated her preparedness to go back to the beginning to rebuild while Jayne was hesitant in attempting the reconstruction of the robot feeling that, "I thought that it was right". She offered a couple of explanations as to why the activity was not successful including an incorrect computer program and "low" batteries in the robot. She did not completely attribute the problem to the construction of the robot until she was about to write in her journal. Jayne's mental models for problem-solving were clearly exhausted (Leviton, 2003) much sooner than Ellen's.

There was an obvious mismatch in the participants' in-action mental models of problem-solving. Ellen believed the cause of the problem to be due to the poorly-constructed robot and "felt kind of bad because no one was listening to me". She was confident that the error was with the construction and repeating the computer programming was, essentially, a waste of time. Jayne held the initial belief that repeating the computer program would correct the problem. Her mental model, at this point, mismatched Ellen's. Once Jayne realised that the error was with the robot construction their mental models matched. However, Jayne's in-action mental model of the robot construction was incomplete (Norman, 1983; Williamson, 1999) as she did not know how to trouble-shoot the process of construction to find the error. The assuredness of the partnership was not being maintained because the students were not working together on a transitory model (Anderson et al., 1996) at a critical time in the lesson, when a joint effort may have guided them to solve the problem. Their use of the psychological tool of language (John-Steiner & Meehan, 2000; Smagorinsky, 1995) was not effectively engaged to negotiate the distribution of the various in-action mental models that were needed to solve the problem.

There was also a mismatch in the control function of mental models. Jayne's in-action mental model of the computer program was controlling her actions to guide Ellen through an activity (Table 5.12) where she felt she had more capable qualifications. Ellen's in-action mental model of the problem indicated that she believed that the computer program itself was not the problem so reviewing it, with or without Jayne pointing the way, would make no difference. Thus, there was no pressure to complete the computer program quickly or to alter anything that had been done. Therefore, Jayne's in-action mental model of the computer program was inaccurate (Leviton, 2003; Williamson, 1999) as she believed that by doing it again and getting it "done in time" would correct the problem. No final, accurate solution to the robot construction problem was found and the activity was not completed successfully.

In Summary

The results of these stimulated recall interviews highlight several key teaching and learning issues. First, young students experience significant difficulties when working on problem situations in pairs or groups. This difficulty can be due to their inability to negotiate a transitory, jointly-held mental model (Anderson et al., 1996) because of the limitation of their working memory. Students require practice to work socially, so that they can exercise the cognitive strategies (Anderson et al., 1996) and the psychological tools (John-Steiner & Meehan, 2000; Smagorinksy, 1995) they have acquired, in order to collaboratively negotiate transitory mental models. The limitation of under-developed working memory can hinder the systematic search for the many alternative solutions (Johnson-Laird et al., 1998) to the problem.

The second significant implication that arises from this area of in-action mental models study is that the compatibility of students in partnerships in a learning situation may have more to do with how they activate their mental models, particularly the predictive, explanatory, and diagnostic functions, than with their ability levels or areas of interest. Compatibility of learners in partnerships or groups may be further enhanced if students are instructed in different possible ways that the mental models they are running can be communicated to others. The diagnostic function of mental models should enable teachers to develop an understanding that students may not be working with in-action mental models that allow them to either assimilate new concepts (Royer et al., 1993) or engage in effective problem-solving strategies as part of their process-outcome predictions (Kyllonen & Shute, 1989). This understanding would enable teachers to assess what in-action mental models students are running during the performance of an activity and take the appropriate intervention for students to develop those mental models that will promote learning.

The third area of importance is the matching of mental models between teachers and their students. It would seem that it is a valid requirement that the teacher understands what in-action mental models the students are running (Royer et al., 1993), so that they can determine when and where there is a mismatch. A mismatch occurred when Pamela focussed on the coding of the activities in the journal and Sam focussed on the content of the journal entry. Pamela’s in-action mental model of the journal included the need for students to keep both a record of their activities and to use numeric coding. Sam’s in-action mental model of the journal encompassed the completion of activities that was the main purpose of his being in the robotics laboratory in the first place! The timing of Pamela’s intervention contributed to Sam’s overloaded working memory. An implication is that, as part of their preparatory training, teachers should be made aware that the information or intervention they are providing is of value to the students’ negotiation of the challenge at hand.

In the examples discussed in this chapter, (a) the view of knowledge in pieces (di Sessa, 1986) or the fragmentary nature of mental models (Henderson & Tallman, 2006) and (b) their analogous link to pieces of a jigsaw puzzle yet to be put together in a coherent way, are quite clear. The evidence highlights the importance of children having multiple opportunities to recognise and run those mental models that will assist them in placing the pieces together to find effective solutions to the problems they encounter in social constructivist learning environments.

The stimulated recall episodes were challenging for the students as were the increasingly difficult programs they were undertaking in robotics. As we follow their footsteps, we also follow the steps of Bilbo Baggins as he trod the often dangerous path to the Misty Mountain. He did not know that the purpose of his journey was to kill a dangerous dragon so that the future balance between good and evil would be tilted slightly in favour of the righteous. At this point in the study, the student participants were equally unaware of how the in-action mental models they were bringing to the robotic experience would guide them through some challenging moments ahead. The following chapters shadow our intrepid problem solvers as they move forward through both complex robotic experiences and unique data collection episodes.

CHAPTER SIX: *Post-Experience Mental Models*

> It was a hard path and a dangerous path, a crooked way and a lonely and a long one. Now they could look back over the lands they had left, laid out behind them and far below (Tolkien, 1937, p. 53).

Introduction

The investigations during the post-experience learning journey through robotics encouraged the participants to reflect on the paths they had trod. The probes offered the opportunity to determine the participants' reflective mental models (Henderson & Tallman, 2006) and to compare them with the espoused and inaction mental models (Henderson & Tallman, 2006).

The data collection methods used to gather the pre-experience data (Chapter 4) were once again used to gather the post-experience data to ensure consistency, rigour, and valid comparison. They included *Likert Scale Questionnaires* (Appendices G and H), *Journals*, and *Semi-Structured Interviews* (Appendices K and L). These different data collection methods were triangulated (Burns, 2000; Miles & Huberman, 1994) to establish a clear picture of those mental models

This chapter presents the analysis of the reflective mental models held by the participants within the categories used in the *Likert Scale Questionnaire* and *Semi-Structured Interviews* to correlate with the pre-experience data in Chapter 4. It discusses reflective mental models of robots, social construction, and problem-solving.

Reflective Mental Models

Conceptual Knowledge

Robots and Robotics

The pre-experience data collection methods exposed the espoused mental models the participants brought to the experience. Pamela's, reflective mental models of the students' reflective mental models of robots was the first step on the pathway to discovering what mental models, if any, had changed throughout the study period. The *Post-Experience, Semi-Structured Interview* with Pamela[5], triangulated with the *Likert Scale Questionnaire*, and *Journal* divulged that she based most of her reflections on her observations of the students' experiences with the

[5] All interview data for Pamela was obtained from the Pre-Experience, Semi-Structured Interview that took place on 5 September 2005.

robotics equipment and her personal interactions with them during those sessions in which she was an active participant.

Teacher.

During the interview Pamela had the opportunity to reveal her assumptions about the students' reflective mental models of robots and robotics when these themes were addressed (Appendix L). She believed the students found the robots easy to interact with because, when constructed and programmed correctly, "they [the robots] did as they were told". She supplemented this observation with the supposition that the students still did not have a strong understanding, at the post-experience point, that "they [the robots] are just a tool" to undertake and complete tasks. Her reflective, post-experience mental model of the children's conceptual knowledge of robots had altered somewhat from her espoused, pre-experience mental model that assumed that the students held mental models of robots as something that "just happen[s]". This slight modification in Pamela's reflective mental model was influenced by her experience of observing the children "teach" or "train" their robots to complete programs. It reflects her beliefs — about the students' interactions with the robotic system— that were acquired through classroom instruction and observations (Norman, 1983).

The robots in the Lego™ Dacta equipment had a microprocessor that enabled them to fulfil the instructions the students programmed with the Robolab™ software. Barker, van Schaik and Hudson (1998) contended that the richer the students' mental models, the more their performance would be enhanced. Here, having knowledge of how robots receive and process commands could have enriched the students' mental models. This may have enabled them to have a clearer understanding of how their actions to construct and program translated into robot action. However, Pamela believed that it was "not essential" for the students to have rich concepts, or mental models, of how robots process information. This knowledge was not fundamental to the students' successful completion of the tasks. She believed that the students, themselves, understood that having a high level of understanding of "how" robots process commands into movement was not essential.

Pamela's philosophy was influenced by a belief, also proposed by O'Malley and Draper (1992), that it is not necessary to internalise some components of a system in order to be able to use it effectively. Leaving some knowledge out there in the world (Norman, 1988) was seen as efficient for learning. Being an effective user of a system, such as robotics, therefore, may not necessitate the performance rigour where complete conceptual understanding of all parts of the system is mandatory.

Pamela's responses to the post-experience *Likert Scale Questionnaire* items regarding the robot-human relationship varied to the responses she provided in the pre-experience questionnaire and these changes are shown in Table 6.1.

Table 6.1: Comparison of teacher's mental models of students' concepts of robots

Pamela's Pre- and Post-Experience Likert Scale Questionnaires

Item number and detail	Strongly Agree	Agree	Unsure	Disagree	Strongly Disagree
16. Students will see robots as being more useful if they respond like humans				**E**	**R**
18. Students will see robots as more useful if they can talk like humans			**E**		**R**
19. Students would rather interact with a robot that is humanlike in appearance	**R**			**E**	

Note. E – Espoused mental model
R – Reflective mental model

The three items in Table 6.1 are of particular interest due to the semantics of the questions and the alteration of response by Pamela. First, Pamela showed a change in response, by moving to the "strongly disagree" position for the two items (16 & 18), whose questions included a reference to "usefulness". Second, while Pamela had disagreed with the assumption that students held a preference for human likeness before they had experienced the robotics activities (Item 19, Table 6.1), she now believed that they held a strong preference for such human appearance. Pamela's comment in the post-experience interview, based on observing students attempts to personalise their robot by attaching Lego™ figures, may account for this change of mental model.

During the post-experience, *Semi-Structured Interview*, Pamela stated that the students have "learnt that robotics ia a functional thing … not necessarily a toy … that we can use as a tool". Pamela's pedagogical philosophy of constructivism (Derry, 1996; Mayer, 1996; von Glaserfeld, 1995), that informed her espoused need to provide the groundwork from which children would build knowledge and understanding, obviously continued to be evident six months later. She believed that the students' investigations through the robotic activities enabled them to gain this conceptual understanding.

Pamela's reference to "tool" functionality in this early part of the post-experience interview was contradicted by a statement, later in the interview, where she observed that the students "don't have a strong understanding of the fact that they [robots] are just a tool". She clarified this second observation by adding that, once the students actually programmed the robots to undertake tasks, they developed reflective mental models that included the concept that robots could have "a huge range of things that they can actually do". This inclusion of programming, that is, "the input of the human being who is controlling the computer" enabled the students to change "what they think a robot is and how it works and what it does" (Pamela, Post-Experience Interview, 5 September, 2005).

Pamela's assessment demonstrated that *informed* mental models were enabling the students to be more effective in the performance of their tasks (Barker, van Schaik, Hudson, et al., 1998). These more effective mental models were the result of the opportunity to engage constructively in learning where mental models are developed as a consequence of active participation in the actual learning experience (Barker, 1999b).

Students.

A discussion of the students' reflective mental models can establish whether Pamela's assumptions were founded on a realistic understanding of the students' mental models. Graphs are utilised, in this chapter, to illustrate the Pre- and Post-Experience Likert Scale responses in a visual form to exemplify simple, comparative data. Interesting responses to Item 17 are shown in Figure 6.1.

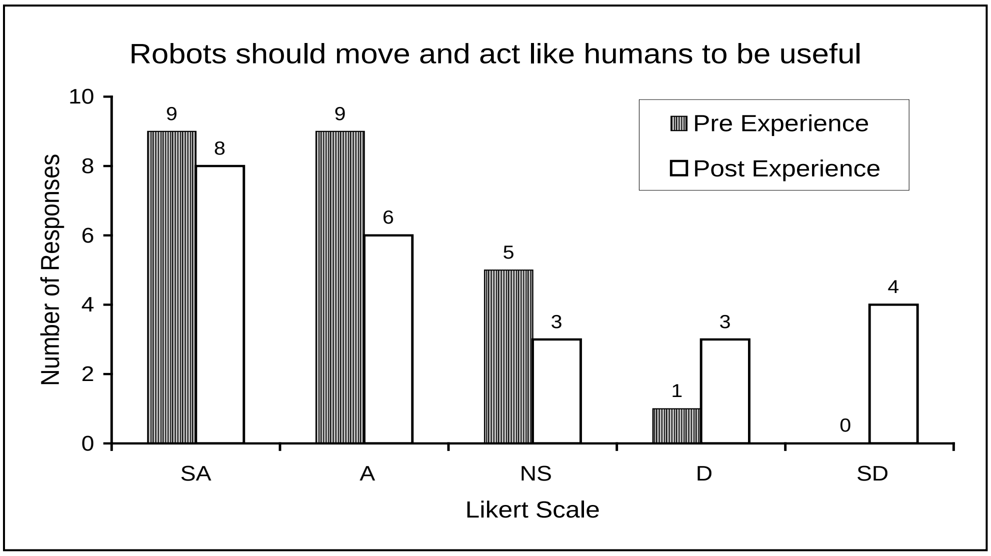

Figure 6.1.Comparison of responses to Item 17 on Pre- and Post-Likert Scale Questionnaire on the usefulness of robots

Responses indicate an overall change from the predictive function of the students' espoused mental models to their reflective mental models regarding the necessity of robots acting like humans to be useful. While there continued to be a predominantly positive response to the statement (Pre N = 18/24; Post N= 14/24), fewer are unsure (Pre N = 5/24; Post N = 3/24) and more have mental models of robot usefulness *not* being attached or related to human qualities (Pre N = 1/24; Post N= 7/24) (Figure 6.1). While the continued positive response does not show a sizeable change (Pre:Post -18:14), the move to a negative mental model of the usefulness of robots acting like humans is noteworthy (Pre:Post – 1:7) (Figure 6.1). Six more students, or one quarter of the 24 in the study group, now did not attribute usefulness of robots to the ability to act like a human with the largest change occurring in the "strongly disagree" scale with an increase of four students. This move to the strongly negative mental model of usefulness attaching to human-like ability to act or respond was a match for Pamela's assumption of the students' mental model shown in Table 6.1.

The alteration in these students' reflective mental models may be attributed to (a) their successful experiences, (b) the social constructivist teaching (Barker, 1999b; Jonassen, 1995; Norman, 1988) they had had with the robots, as well as (c) the fact that their robots moved on wheels (Figure 6.2) while responding to commands programmed by the students through the computer. The robots moved like robots.

Figure 6.2 Example of robot [RCX] used in the activities associated with the study where wheels form the foundation of movement. Image ©2010 The LEGO Group. Used with permission.

The students had been constructing functional cognitive representations (Johnson-Laird, 1983; Johnson-Laird & Byrne, 1991) of the phenomena, robots, with which they were interacting. Apparently, the students' mental models now contained the relevant semantic information that was required for knowledge to be processed to solve construction and programming problems. Hence, it would be expected that the students would be less inclined to hold reflective mental models that saw robots being more useful if they could move and act like humans if they had experienced success working with ones that did not possess those characteristics but were, nonetheless, able to complete the required tasks.

The need for robots to be able to do more than one thing was also addressed in the Post-Experience *Likert Scale Questionnaire* and the responses in Figure 6.3 showed only slight variation between the two questionnaires.

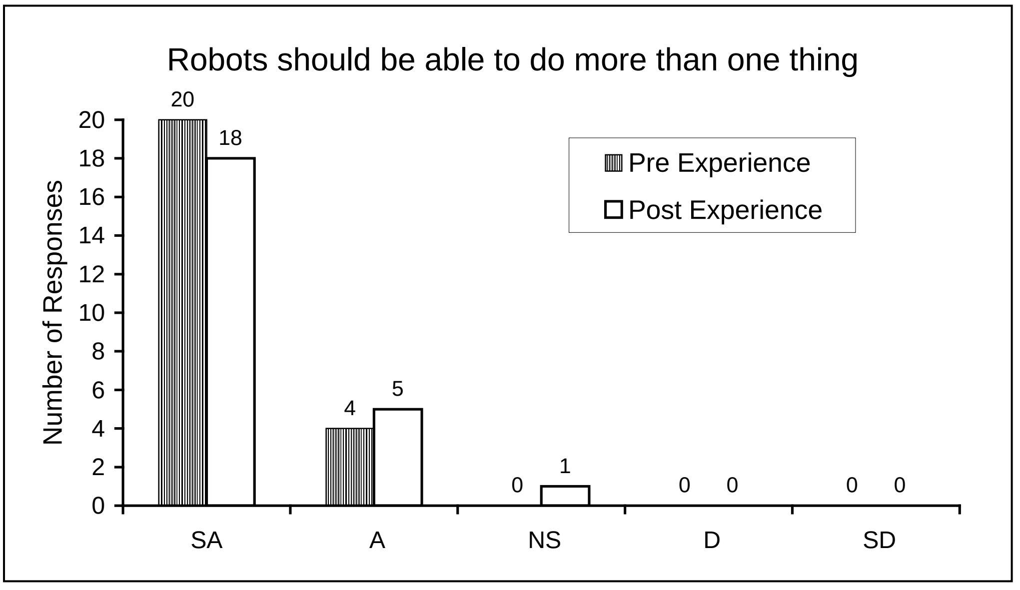

Figure 6.3 Comparison of responses to Item 6 on Pre- and Post-Likert Scale Questionnaire on the ability of robots to do more than one thing

The constancy of responses to this item indicates that the students continued to hold mental models associating a robot's usefulness with its capacity to multi-task. While multi-tasking capabilities were not provided, the need to include more than one purposeful function may reflect the post-modernist (Poyner, 2003) view of design that requires products to fulfil more than one role, such as telephones that take photographs. The students' espoused and subsequent reflective mental models, of the usefulness of the ability to perform more than one task, were informed either by the media and home experiences of robots in their lives (Barker, 1999b; Norman, 1983) or through their own interactions in the robotics learning experience. Barker (1999b) and Barker, van Schaik, Hudson, et al. (1998) proposed that the multitude of experiences and environments in which we interact can generate the stimuli required to activate existing mental models, modify them, and create new ones.

The perceived usefulness of a robot's ability to talk was also addressed in both Pre- and Post-Experience Likert Scale Questionnaires. Once again, there was very little variation between the students' mental models (Figure 6.4).

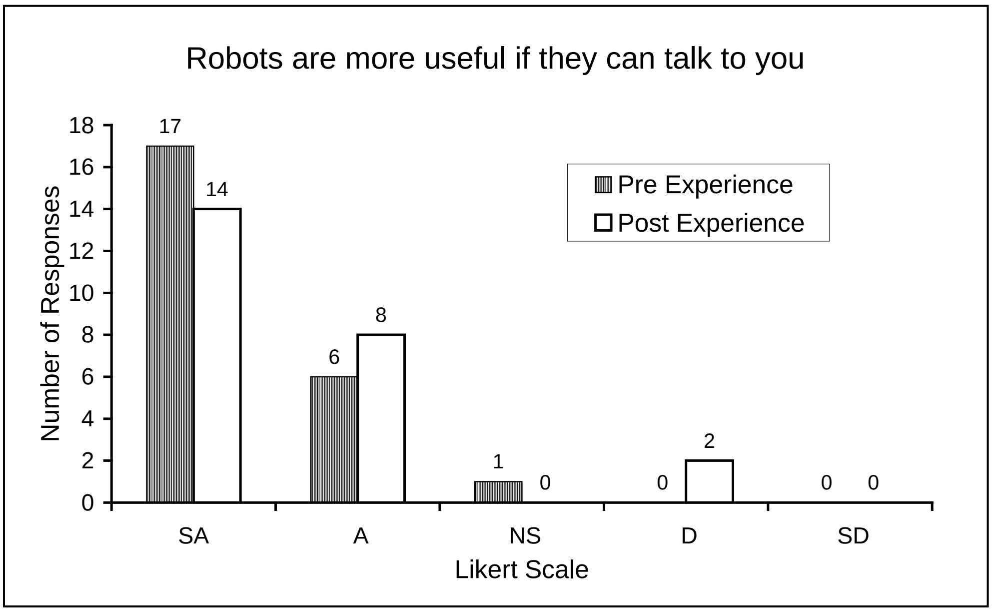

Figure 6.4 Comparison of responses to Item19 on Pre- and Post-Likert Scale Questionnaire on the usefulness of robots who can talk

This could be because of their limited experience with robots prior to the commencement of the robotic experience and their current experiences in the classroom with robots that cannot talk. Only two children, including Sam, believed that talking robots were not more useful and this mirrored Pamela's mental model predictions of the students' mental models. While Pamela's espoused mental model was unsure of these students' views, her reflective mental model was being informed by her observations of the students' classroom interactions with the robots.

Pamela's "informed" prediction in the Post-Experience Likert Scale Questionnaire highlights a significant mismatch with that of the students. This has important implications for teachers. Teachers may develop instructional episodes that have an incorrect focus or premise if they make erroneous assumptions about students' mental models (Stripling, 1995). In this case, the mismatch highlighted the fundamental difference in how students would view the usefulness of the robot and the context of that usefulness.

The four participants were individually interviewed over a two-day period six months[6] after the commencement of the robotics learning experience (Appendices K

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[6] All Post-Experience, Semi-Structured Interview data with students comes from interviews held on 5 September 2005 (Ellen and Jayne) and 6 September 2005 (Bree and Sam).

and L). The Post-Experience *Likert Scale Questionnaire* (Appendices G and H) was administered in the same week as the interviews. At this time, the students were asked what materials they believed were required to make a robot. Their pre-experience multiple responses are shown alongside comparative results to their post-experience responses (Pre:Post), contain materials such as: Lego™ (1: 4), plastic (0:3), wires (1:2), metal (1:1), batteries (1:1), and rubber (0:1). There were two noticeable Pre-Post changes in the responses. Firstly, no student proposed plastic as being a functional construction material for robots in the pre-experience interview while three of them, after experiences with plastic components (Lego™ blocks), included it in their reflective mental model. Secondly, all students (4) gave Lego™ as a response in the post-experience interview that indicated that they were now carrying “small scale models” in their minds (Craik, 1943) of the robotics experience.

The questions about what robots actually do uncovered greater variation in response. While Ellen, Jayne, and Bree had reflective mental models that included a domestic reality of robots being used to play music, wash clothes, clean dishes, and get food, Sam’s reflective mental model appeared much more conversant with global realities. He had seen a television program that showed robots being made that “look like humans” and “learn from what humans do”. He was aware that they help the police and armed forces by observing people and places via remote control so that humans are less exposed to danger. Sam’s reflective mental model contained concepts that information about robots was found via the television and that robots were in the Federal Bureau of Investigation (FBI) and the army, thereby indicating his broader conceptual knowledge of the functionality of robots.

The students were asked to provide a definition of a robot and their responses are shown in Table 6.2.

Table 6.2: Student responses to “What is a robot?”

Student	Response
Bree	A robot is what you could use for researching things, like a computer.
Ellen	A robot is a piece of hard drive that makes life easier for humans.
Jayne	Like a little animal, sometimes, because it moves around and does stuff and is quite clever.
Sam	A robot is a reprogrammable piece of equipment. Something that is useful.

Jayne was the only student who likened a robot to a living creature thus demonstrating a reflective mental model of robots that was still quite naïve. Jayne had not connected the construction materials required with functionality in order to reformulate a more expert mental model that would generate an adequate analogous structure (Newton, 1996). Jayne proposed that you can “train them properly” to “do chores for you” that may reflect her “animal” analogy, but this was as close as she came to giving a definitive definition. Her use of pedagogic language, such as “teach” and “train”, in relation to robots, was influenced by Pamela’s use of language. This absorption of terminology into the students’ mental models makes sense in accordance with Norman’s (1988) recognition that individuals create or form their mental models through “experience, training and instruction” (p. 17) and Barker’s (1999a) concurrence that mental models are formed as a consequence of activity within a domain. In comparison with the other three students’ mental models, Jayne’s novice mental models of robots appeared to lack the “repertoire of relevant clusters” (Newton, 1996, p. 206) that prohibited her from providing an apposite description of robots. Because these descriptions were all that Jayne could provide when probed about what a robot is (Appendix K), her mental model was likely to remain inert (Newton, 1996) and, thus, was unlikely to be enhanced if she remained unwilling to critique this simple idiosyncratic mental model to consider alternatives.

Robotics – Programming and Intelligence

The students constructed and programmed the robots, in the preliminary activities, in order to undertake pre-determined tasks that primarily involved movement in a certain direction for a given period of time. The pilot programs gave specific instructions for these variables and there was a clear link between the instructions and the resultant physical action. The Pre- and Post-Experience Likert Scale Questionnaires (Appendices E and G) asked the 24 students to respond to the Figure 6.5’s statement: “Robots have brains that are similar to ours” (see next page).

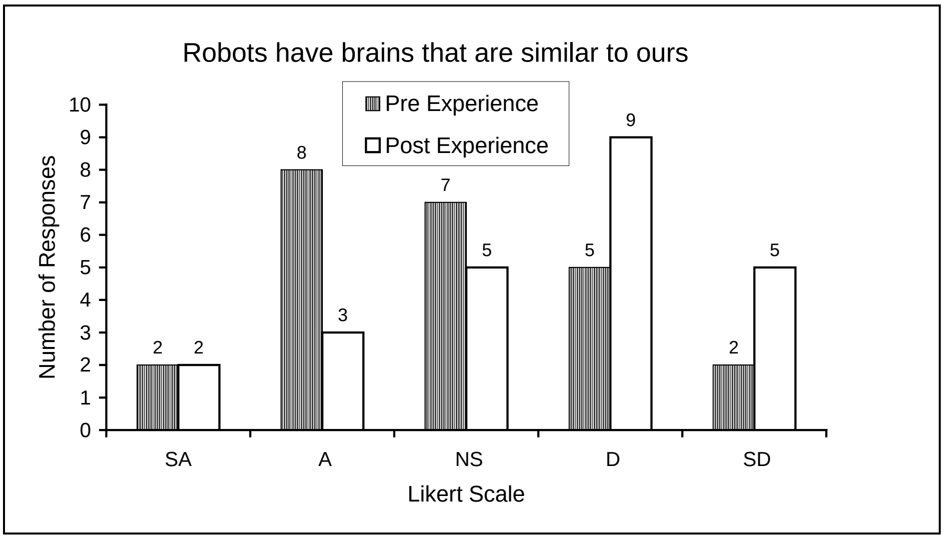

Figure 6.5 Comparison of responses to Item 24 on Pre- and Post-Likert Scale Questionnaire about robots having brains similar to those of humans

There was a distinct move toward the negative in the post-experience responses (Figure 6.5). Of the four interview participants, three disagreed with the idea of similarity, while one was unsure. This move may indicate that for these students, their class experiences informed their reflective mental models about the link between what programmers do on computers and the subsequent robot's actions. If understanding is a mental state that results from the process that infers relationships between different elements of information (Newton, 1996), then the 14 students' understanding of how robots "think" has become part of their mental models. The students were required to generate a plausible explanation of robot's cognitive capacity in comparison with that of a human. Nevertheless, the term, "similar", could be problematic and would therefore benefit from targeted clarification and this was addressed in the semi-structured interviews.

Even Jayne's reflective mental models about robotic intelligence demonstrated significant changes from those revealed in the pre-experience interviews, with less emphasis on a robot requiring the ability to hear instructions and a stronger focus on a robot's structural components that enabled it to physically respond (Table 6.3; see next page).

Table 6.3: Student responses about thinking ability and brain function of robots.

Student	Response
Bree	Memory chips and computer chips.
Ellen	They probably have mechanical things that make it think.

Student	Response
Jayne	They had a light sensor and a touch sensor. They could look for the light and they could look for dark. When they see dark, they can see.
Sam	They have like a memory hard drive or something.

Jayne was the only interviewee who continued to be unsure of how robots think in the post-experience data collection period. Her interview responses were repetitious and included suggestions of what robots could do to help, such as “pick up stuff and move stuff with their arms” and “can walk and talk” — not how they think. Jayne’s post-experience response was particularly disturbing when compared with the one she provided in the Pre-Experience, Semi-Structured interview in March 2005 where she stated, “They don’t have a brain like us”. It would appear that Jayne had moved from certainty, prior to the experience about robot intelligence, to uncertainty at the post-experience point. During the post-experience interview, she could not suggest places where robots were used, had “not really heard of robots” in a factory, and only recognised robots as toys and artefacts in the learning experience and on television. Table 6.3 shows some of Jayne’s responses to how the robots in the school learning experience responded rather than their specific “cognitive” functionality.

The responses by Bree, Ellen, and Sam show more systemic, conceptual mental models of the mechanisation of the thinking process of robots than does Jayne’s mental model. Bree further explained the functionality of memory chips by stating that they “hold a lot more things . . . and it makes them do more advanced things than we can” (Table 6.3). This explanation illustrates that her reflective mental model has incorporated the idea of the limitation of human memory compared with a physical limitation of storage on computer memory chips. Sam offered limited clarification of his reflective mental models of robots by stating that “robots aren’t used for the same things that humans usually do” and that humans are “only making robots now to do stuff that we can’t do”. This reflective mental model also incorporated Sam's responses concerning the locations for robotic functionality: law enforcement situations that require complicated and dangerous engagements.

The mental models of artificial intelligence held by students are of significant interest to the developers of robotic equipment for classroom use. These issues should also concern the classroom teacher who adopts a discovery-centred curriculum where students are exposed to activities that involve programming and construction of artefacts to complete tasks. The philosophical and ethical questions of what constitute "artificiality" of robot construction and intelligence is beyond the scope of this paper. However, the implications of the cognitive view of artificiality can be clearly seen in the results of this investigation. Teachers cannot assume homogeneity of mental models (Jonassen, 1995) of robotic intelligence within cohorts of students, even after six months of learning with robotics. Such erroneous assumptions would deny the existence of students, who are attempting to interact effectively within the domain, with idiosyncratic mental models that are deficient in conceptual knowledge of robot functionality and intelligence.

Richness of the Robotic Environment

The data collected demonstrates that the 24 students developed more realistic reflective mental models of robots after negotiating the learning experiences that involved the construction and programming of their own robots. When responding to interview probes about how robots know how to perform various tasks, interesting terms used by the four interviewees were "train" or "learn": robots were "trained" to move a certain way or they "learned" how to spin in a circle. This use of pedagogical terminology indicated some human cognitive process and seemed at odds with the programming they were undertaking with the robotic software. It was unclear as to where this terminology originated until Pamela mentioned, during her Post-Experience, Semi-Structured Interview, that the students were going to "teach it [the robot] to do" certain tasks. She used the term, "teach", with the students and they associated that with "train" and "learn", hence the constant use of these terms in the interviews. Pamela was thinking aloud and encouraging her students to use this strategy in their problem-solving (Clark, Aster & Hession, 1987), they then were incorporating this use of terminology into their mental models. The language was becoming part of a cultural tool (Smagorinsky, 1995) of the robotics environment and forming their conceptual understanding (Barker, 1999a; Newton, 1996; Norman, 1983).

Pamela believed some of the greatest learning, and therefore changes in students' mental models, was "the realization that they have to give it [the robot] instructions before it'll do what it's supposed to do" and that the idea that "it [the robot] has independent thought has changed" (Pamela, Post-Experience Interview, 5 September 2005). She also believed that generally all of the students started to see themselves as "inventors" who were engaged in an "open-ended" activity that involved problem-solving and getting along with others. It was not determined if the interviewed students held this mental model of themselves as this information was not available before each was interviewed. If they had altered their mental models it was because they were willing to reformulate and restructure, or manage (Henderson & Tallman, 2006), their mental models that called for a mix of conceptual, "declarative, procedural, strategies, beliefs and metacognitive control" (Newton, 1996, p.206). Any alteration of reflective mental models also required the act of sharing personal mental models through social interaction (Henderson & Tallman, 2006). Moving now to the reflective mental models of social construction, the importance of those socially negotiated, problem-solving skills are visible.

Reflective Mental Models

Social Construction

While the paired organisational structure ensured that all students could engage in the robotic activities in a timely manner, it also supported pedagogy that acknowledged the social construction of knowledge (Chapters 4 and 5). The mental models, that the students were running to work their way through the programs within the robotics learning experience, were products of, and processes within, their social and physical interactions with their environment (Anderson et al., 1996) and their external and internal dialogues (Barker, van Schaik, Hudson, et al., 1998). They would be running mental models that should enabled them to negotiate both the robotics program and the social interactions that they would encounter throughout the experience.

One of the items on the teacher's Pre- and Post-Experience Likert Scale Questionnaire (Appendix F and H) addressed her perception of whether students learned more when working in a group or when working alone. Pamela responded affirmatively in both questionnaires as it supported her pedagogical practice of social constructivism and cognitive apprenticeship (Dickey, 2008; Seely Brown, Collins & Duguid, 1989). Thus, her espoused and reflective mental models remained constant with this theoretical view of knowledge construction (Herrington, Reeves & Oliver, 2006).

Pamela understood herself to be a "sequential thinker" when problem-solving in teams but believed that most of the students "look at things from a different point of view" because "they jump all over the place" (Pamela, Post-Experience Interview, 5 September 2005). Their methodology of group problem-solving was of particular interest. Therefore, in order to understand the students' idiosyncratic ways of working in groups, Pamela spent a significant portion of each robotics lesson observing how they worked together. She found that there were differences between how the students worked and that some of them were more inclined to do the computer programming while others were happier constructing the robot.

Although Pamela did not teach the students how to negotiate these roles, she witnessed a natural tendency within the cohort of 54 students to "cluster in fours . . . an amazing phenomenon" when students realised they were working on the same part of the program and melded their pairs in order to accomplish the task. Pamela proposed that "they were actually happier to work in a bigger group of four, even though they had to share equipment" and that these groups did not necessarily reflect friendship preferences. The reason was not due to the lack of equipment or the reality of sharing. Pamela observed that the students "clustered around one expert" because they were "naturally drawn to that person" to achieve their goal. It also indicates that at least some were operating with mental models that recognised expert knowledge and skills in others, that encouraged some negotiation of space and equipment in order to accomplish a task. This student-negotiated grouping also enabled the students to get "through the process quicker" (a time efficiency student mental model) and to "set their own pace" (a maximisation of learning student mental model).

In their study, Anderson et al. (1996) discovered that students' jointly-shared mental models were more effective than an individually-held one and the actions of Pamela's students indicate that the continued desire to work in larger groups was proving beneficial to their ability to negotiate the learning experiences. Pamela believed that the students "absolutely" liked working in groups and "only five or six" students, including Sam, preferred to work on their own. Pamela's close, class scrutiny informed her reflective mental model of individual constructivism and social constructivism as she would "differentiate those kids and put them on their own" in the future.

Generally, Pamela exhibited a reflective mental model of social construction that matched those of the students. She held a pragmatic view of the need for efficiency within the robotics learning experience due to the lack of equipment, space, and time. Efficiency had informed her grouping of students and the time they would have to complete their activities. Organisational mental models cannot be parallel to pedagogical best practice mental models because they are inexorably linked and must, therefore, influence the experiences more strongly than teachers would sometimes wish.

The students had much to say about working in groups or pairs. Seventeen of the 24 students held a reflective mental model of learning more in a group by responding positively, but not as strongly, to the Likert Scale Questionnaire Item (Figure 6.6). There is a noticeable movement of students in the unsure (5:2) and disagree (2:5) responses.

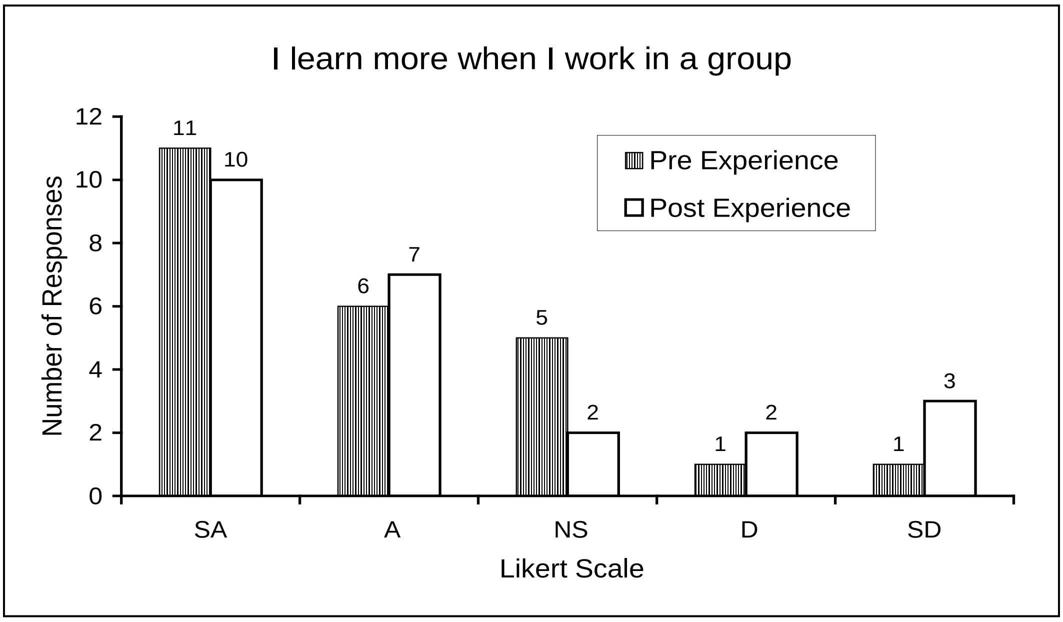

Figure 6.6 Comparison of responses to Item12 on Pre- and Post-Likert Scale Questionnaire about learning more when working in a group.

The evidence of this noticeable shift from "uncertainty" to "negativity" may indicate that some students did not experience the positive aspects of social constructivism (Vygotsky, 1978) that Pamela anticipated and believed occurred in her post-experience interview. Wertsch (1985) argued that the classroom settings established by a teacher are governed by assumptions that "determine the selection of actions and their operational composition" (p. 212). Pamela's assumptions about grouping students, while including the recognition of some students' preference to work alone, continued to direct "the physical, social, and instructional environments … [her class space] … in order to direct students' [cognitive and social] development toward particular ends" (Smagorinsky & O'Donnell-Allen, 2000, p. 166).

Two of the four students interviewed had completely reversed their responses; Ellen moved from disagreeing to agreeing and Bree from agreeing to disagreeing (Figure 6.6). Ellen's reflective mental model demonstrated her belief that working in a pair now benefited her learning. Ellen's experience of working in a pair with another female study participant, contributed to a positive outcome of their previous conflict (Chapter 5) of social mediation (Ball, 2000) while, simultaneously, creating and adapting her mental models of robotics. Jayne, who worked in a group of three female students, one of whom was not part of the study, also expressed positive mental models of working socially and, therefore, neither Ellen or Jayne's responses will be addressed in depth. Bree and Sam offered responses that hold significant implications for teachers.

Bree, who worked in a pair with a male study participant, responded by providing a strongly positive response in the pre-experience and a strongly negative one in the post-experience questionnaire. This signals the need for intervention from Pamela. Guidance is required so that Bree can commence to interpret the tasks to complete in a more proactive or common way (Putney, Green, Dixon, Duran, & Yeager, 2000) by learning how to share her mental models of robotics (Anderson et al., 1996) with her partner. Students who work in pairs do not "simply internalise" (Ball, 2000, p. 115) what it is they are required to achieve together, such as trouble-shooting problematic robot construction jointly, rather than leaving it to one individual. Students need to be shown the steps to take with people in their group that will enable social interaction to promote cognitive functions.

Bree's reflective mental model of working in groups was articulated during the Post-Experience Semi-Structured Interview. This clarification demonstrates the weakness of this and, perhaps, any Likert Scale Questionnaire compared with the usefulness of the interview to gain quality information about particular issues such as working in pairs from an individual's point of view. Bree's negative response on the Likert Scale Questionnaire was tempered during the interview where she acknowledged that “working in groups can help as long as I’m with positive people”. Bree found that negative students “don’t do much work” and are “not cooperative”. Bree also acknowledged that sometimes she talked too much when working with others and consequently needed to “ignore conversations not about the robots” in order to finish her work. Her reflective mental model contained either realistic self-perception or self-knowledge production (Gutierrez & Stone, 2000) because she further acknowledged that working in groups can be fun and that you can “get the job done a lot quicker … so you can go on to the next one”. This focus on getting the job done more efficiently is supported by Anderson et al.’s (1996) research about the effectiveness of children’s jointly-shared mental models.

While Sam agreed that he learned more when he worked in a group (Figure 6.6), his responses in the Post-Experience, Semi-Structured Interview provided a negative mental model of group work. Sam found that, while working in groups was good sometimes, it was not fun if you did not get on with the people with whom you were working. “[I like] to work on my own most of the time,” he acknowledged, but “sometimes you don’t get a choice”. Working in groups was “okay” if you had “problems with programming” but not okay if “you’re always arguing with people”. Sam explained the arguments involved disagreements about where parts were meant to be placed on the robot. He became annoyed when he would try to explain the correct way of constructing a robot to his partner, a male study participant, or other students who sometimes worked with them, and they would not listen.

Sam’s annoyance provides evidence that he is operating with a reflective mental model of social construction that situates himself as the “expert” within his group; the sage on the stage in a cognitive apprenticeship context (Seely et al., 1989; Vygotsky, 1978). As the sage, he believes he can be equally successful when learning on his own. While Sam appreciates the opportunity to work with others, his perceived value of such interactions is dependent on his personal academic and social needs and his desire to be the ‘expert’, and is not a prerequisite for mastery of learning. This mental model of social construction reflects the attitudes of high achievers to group work in Schmakel’s (2008) research. It found that, while complicated projects helped motivate high achievers, the act of working in a group helped them to negotiate the difficult problems they encountered when working alone.

The students' responses to the question of working in groups in problem-solving scenarios, such as robotics, raises important questions for teachers in view of the effectiveness of students to negotiate a problem situation while negotiating a social one. Anderson et al. (1996) questioned the ability of students, of a similar age to the ones in this study, to work in group situations where they may overload their working memory by attempting to handle the social interactions of the group while simultaneously attempting to run suitable mental models to solve the problem. The constant negotiation of a transitory mental model (Anderson et al., 1996) would necessitate appropriate and effective mental models for the problem being encountered and for the social negotiation taking place. The social interactions evident in group work may require students to deal with cognitive and social dissonance both of which may fragment appropriate mental models and make them unusable in problem-solving.

Given this research, it was important to establish the students' perception of the outcomes of social construction. Hence, the Pre- and Post-Experience Likert Scale Questionnaires (Figure 6.7) asked the students if they felt that the robot they would make in a group would be better than the one they would have made while working on their own.

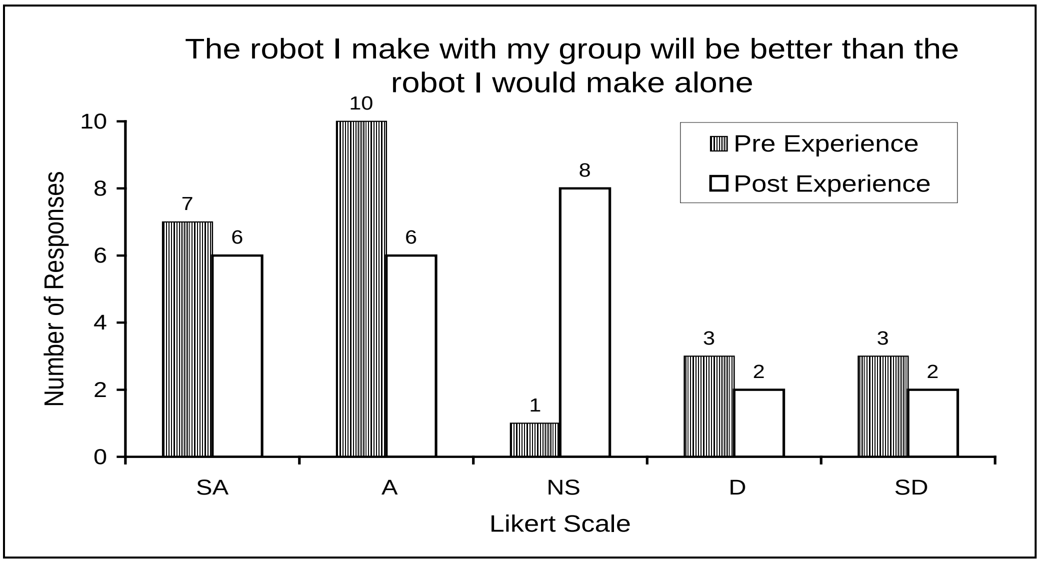

Figure 6.7 Comparison of responses to Item13 on Pre- and Post-Likert Scale Questionnaire about learning more when working in a group.

The responses to this question (Figure 6.7) were some of the most interesting due to the increase in students (1:8) who were now "unsure" of whether the robot they made with their group would be better than one they made individually. The

Pre:Post results for agreeing show 17:12 indicating a reduction by five in the post-experience questionnaire.

Sam was the only interview participant who agreed with the better quality of a robot made with a group on the post-experience item. The other three participants, Bree, Ellen, and Jayne, were all now “unsure” and their responses contributed to the significant response change seen for “NS” [not sure] in Figure 6.7. All student interviewees had altered their espoused mental model: Bree and Jayne had agreed, Ellen had disagreed, and Sam had been unsure. This question provided the largest number of unsure responses on the 40-item Post-Experience Likert Scale Questionnaire (Appendix G).

The uncertainty of the comparative quality of the robot created individually or with a group may be attributed to the mental models the students had now developed of group members’ perceived skill levels. As previously mentioned, Pamela had noted that students were grouping together in larger groups and sourcing individual students as perceived “experts” to help them complete their tasks. Quite possibly, they were making larger groups to negate a partner’s ineffective mental models for programming or construction that may have been restricting their progress (Fischbein, Tirosh, Stavy & Oster, 1990) in successful decision making in problem situations (Sloboda, 1996). The results of these investigations pose significant issues for teachers to be aware of and address when adopting social constructivist practices in the classroom.

Assessment and Predictions of Success

One of the functions of mental models is to inform the learner of the possible outcomes of the operational strategies they are using (Johnson-Laird, 1983; Norman, 1983). The mental models the students were using during the robotics experience engaged propositional representations to enable them to predict the outcomes of the strategies they used to complete the tasks (Goodwin & Johnson-Laird, 2008; Kyllonen & Shute, 1989; Vosniadou, Skopeliti & Ikospentaki, 2004). This ability to predict the likely success of actions is a fundamental aspect of running mental models and plays an important role by helping the student investigate alternatives as they explore a problem (Carley & Palmquist, 1992; Renk et al., 1994). Exposure to robotic software programming and construction, during the six months since the beginning of the learning experience, should have enabled the students to develop a functional foundation of knowledge in the domain. This foundation should include increasingly robust mental models to enable the students to reason through the strategies they use for construction, programming, and social construction. This purposeful development and engagement of mental models should also have enabled them to begin to eliminate those mental models that were redundant for efficient problem-solving (Bibby, 1992). The outcome of such purposeful engagement of mental models should see improved "model-task match" (Bibby, 1992) where students retained more "good" matches and removed "poor" matches in their problem solving strategies (p. 166).

Investigations into predictions of success involved the repetition of questions asked in the pre-experience data collection instruments. Additional questions requiring reflection on the success of their experiences were included to determine the reflective mental models of personal assessment and the successful, or otherwise, implementation of strategies. The following section first discusses Pamela's assessment strategies, and then investigates the students' mental models.

Teacher.

Pamela was questioned specifically about her assessment strategies during the Post-Experience, Semi-Structured Interview on 5 September 2005. Her responses confirmed that she adhered to social constructive pedagogy and assessment by using many strategies. Her overarching assessment epistemology supported the exclusion of competition among students. The absence of such a competitive environment would enable students to undertake self-paced learning where they "didn't compete at all, because they just had to work through with what they had to work with". It promoted the idea that knowledge can be used to negotiate novel problem situations in a socially-supportive environment.

Responding to probes regarding the format of assessment, Pamela argued that the most useful instrument to use is "conferencing". This was included in her current curriculum plan as the summative assessment strategy. The teacher/student conference would entail sitting with each student and having a conversation that included "very specific questions" that she would prepare in advance. The conference, therefore, was seen as the primary social constructivist assessment strategy to use in determining the learning journey of each student.

Pamela's secondary strategy was the use of the students' journals. This formative assessment strategy would explain "the journey that they have been on"

(Pamela, Post-Experience Interview, 5 September, 2005). Pamela was “more interested in how they feel about the experience”, that is the affective knowledge they were gaining about themselves. This method of determining both the quantitative (how many programs attempted and completed) and qualitative (how they felt about their strategies) (Royer et al., 1993) aspects of the students’ performances would enable Pamela to see what strategies they were using when they met challenges. The journal allowed Pamela to determine the diagnostic functionality (Royer et al., 1993; Williamson, 1999) of the students’ mental models and therefore would provide an important formative assessment instrument (McLaren, 2007) that could aid student progress through the activities.

An open day, to celebrate the end of the second unit of work for the year, was arranged in August 2005, where students showed their robot constructions to parents and other interested guests. Three units of work were covered in one year from February to December. Robotics was a continual activity throughout the year and throughout each unit and it was anticipated, by Pamela, that by August/September most students would have finished the basic programming activities. For the August open day, there was no focus on the completed robotic “product” to provide evidence of students’ capabilities in this domain. Pamela summarised:

> The end product is not the end goal. It’s to teach these kids that you take things step by step and you learn about things as you go along, and that learning builds on the prior learning and so, as you go through the process, you’re armed with what you need to do to the product. The robot is not the product. The product is actually getting the robot to work and to do what they’d asked it to do. (Pamela, Post-Experience Interview, 5 September, 2005).

This message of achieving “goals” was clearly communicated to the students at the beginning and end of each lesson when they were given time to record their pre-lesson goals and post-lesson achievements and thoughts (both pre- and/or post-lesson) in their journals. Whether or not the students used their journals to fully express their success and frustrations would be a pertinent issue. Pamela had expressed some concern about this during the in-action data collection episodes where stimulated recall was used to determine the mental models run by the participants in July 2005 (Chapter 5). Pamela acknowledged, first, that the students’ literacy abilities would influence their fluency in expressing themselves as fully as they could and, second, that any limitation in such skills might impact on the usefulness of the journal as a strategic assessment instrument. She had a realistic view of student engagement by stating that “when you’ve got a cohort of 52 kids, you can’t expect that you’re going to get 52 successful stories” [Note: two children had left this cohort since the beginning of the robotics activities, see Chapter 3: Participants].

By 5 September 2005 when she was interviewed, Pamela had not conducted the teacher–student interviews but she had read the students’ journal on a regular basis to inform her of their individual progress. She proposed, at this point, that the most important learning the students had undertaken was to realise that they could “persevere with things”, “to be a group member”, and “to actually believe they can” do the task. Pamela would continue to look at “the journey that they’ve taken as opposed to the products they’ve produced” and that this would be formalised through the interview. This discourse feedback would facilitate insight into the dynamics of this group’s learning journey and subsequently enable her to arrange future learning experiences.

Students.

The students were not specifically asked to address issues of assessment during this post-experience data collection episode in September 2005. Rather, they were probed for their mental models of prediction and attainment of success after completing the basic programming activities. A more specific focus on assessment was scheduled for a later data collection episode in November 2005 (Chapter 7). A further two months of working on more advanced robotics activities would provide the students with experiences from which to draw mental models for assessment (see timeline, Figure 3.2, Chapter 3) and to compare these with their predictions.

The motivation to be proactive in a self-paced learning experience can depend on how students perceive their success (Anderman, et al., 1999). It was, therefore, important to provide research opportunities for students to evaluate their personal robotics skills so as to stimulate the accuracy of such perception. This targeted Research Objective Two that sought to discover the espoused, in-action, and reflective mental models of learning and assessment with a particular focus here on the personal evaluation of learning in robotics.

The Pre-Experience Likert Scale Questionnaire (Appendix E) conducted on 10 March 2005 asked the students if they believed they had the skills required to make a robot. The post-experience questionnaire (Appendix G) implemented six months later on 8 September 2005 repeated this item to determine their perception of skills after they had had the opportunity to develop them (Figure 6.8).

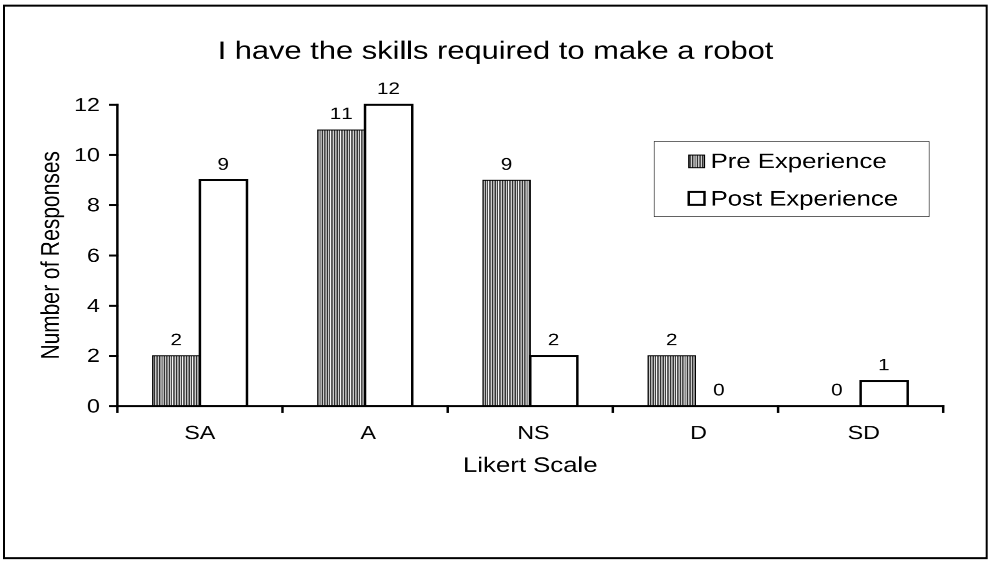

Figure 6.8 Comparison of responses to Item 2 on Pre- and Post-Likert Scale Questionnaire about having the skills to make a robot.

The most significant changes in the responses to the question about skills were in the strongly agree and unsure categories: seven more students (N=9/24) now strongly agreed that they had the required skills and seven fewer (N=2/24) were not sure. Bree and Ellen had felt “unsure” in the pre-experience questionnaire in March but now strongly agreed with the item. Both Sam, who strongly agreed, and Jayne, who agreed, had not altered their response between the two data collection periods that may indicate that nothing had occurred during their experiences to create a change in their mental model of competence in new domains. All interview participants now had confidence that they had the skills to make a robot.

However, how successful had the students felt during the robotics experience? This was a question added to the post-experience Likert Scale Questionnaire to access their reflective mental models of success (Table 6.4; see next

Table 6.4: Student responses on the success of their experiences with robots

Question 33: My experiences with constructing a robot were successful.					
	Strongly Agree	Agree	Unsure	Disagree	Strongly Disagree
Responses	11	8	3	2	0

While most students (N=19/24), including Bree, Ellen, and Sam, felt that they had experienced success in the learning experience of constructing robots, three classmates were unsure. One of these was Jayne. Jayne explained more fully her reflective mental model of success: “On the lower missions it was quite easy and then it started to get harder and harder” and, when asked for her overall reflection of her success, she explained that it was “quite” successful “most of the time” (Jayne, Post-Experience Interview, 5 September 2005). This response indicates that Jayne’s mental model of success is interwoven with mental models for completing the robotics missions. In order to establish a mental model of success, a mental model of a domain (Newton, 1996) and what determines accomplishment of the conceptual, declarative, and procedural knowledge (Barker, van Schaik, & Hudson, 1998) required to operate effectively within it are required. An example would be Jayne’s need to have developed the conceptual, declarative, and procedural knowledge of how to construct a functional robot ready to accept and enact a program for which its construction was valid for the construction aspect of robotics. Her uncertainty as to her skill in this area was demonstrated clearly in the teach-back episode (Chapter 7).

The other three semi-structured interview participants had varied responses, although they all responded in the affirmative to the Likert Scale item above. Bree’s reflective mental models are also worthy of note for the implications they pose for teachers. She exteriorised these mental models (Post-Experience, Semi-Structured Interview, 6 September 2005) revealing that, when she started, she believed she “wouldn’t get up this far” with programming and construction. This mental model was based on the understanding that she “didn’t know much about robots and what they did”. She described how, “about halfway through my third one, I said to myself, ‘This is easier than I thought’!” When questioned as to how she came to feel this way, Bree offered several reasons including that the teacher had “taught us all about the robots”, and that she “had the opportunity to program the robot” with her partner because “we programmed it together”. This multiple reasoning for success indicates two important implications for classroom organisation and pedagogical practice: scaffolding instruction for learning and a social constructivist environment.

Firstly, the pedagogical strategies used by Pamela to scaffold social-constructivist learning (Brown & Palincsar, 1989), where specific strategies were modelled and then support gradually removed, had proven effective for Bree as she was able to construct successful mental models of robotics. Secondly, the use of social constructivism (Vygotsky, 1978) was beneficial in assisting Bree to experience success by enabling her to develop mental models of the domain and of the social arbitration necessary to negotiate jointly shared mental models (Bibby, 1992) within that domain.

A strategy, for engaging students in classroom activities and enhancing their motivation to develop robust mental models while doing so, is to provide challenging activities, such as those in the robotics program used in this study. While a negative perspective of a "challenging" activity may preclude some students from participating without alacrity, many students relish the opportunity to engage in a discovery-based experience that is of high-interest (Jonassen, 1995; Papert, 1980; Schmakel, 2008). This informed Item 11 in both the Pre- and Post-Experience Likert Scale Questionnaires (Figure 6.9).

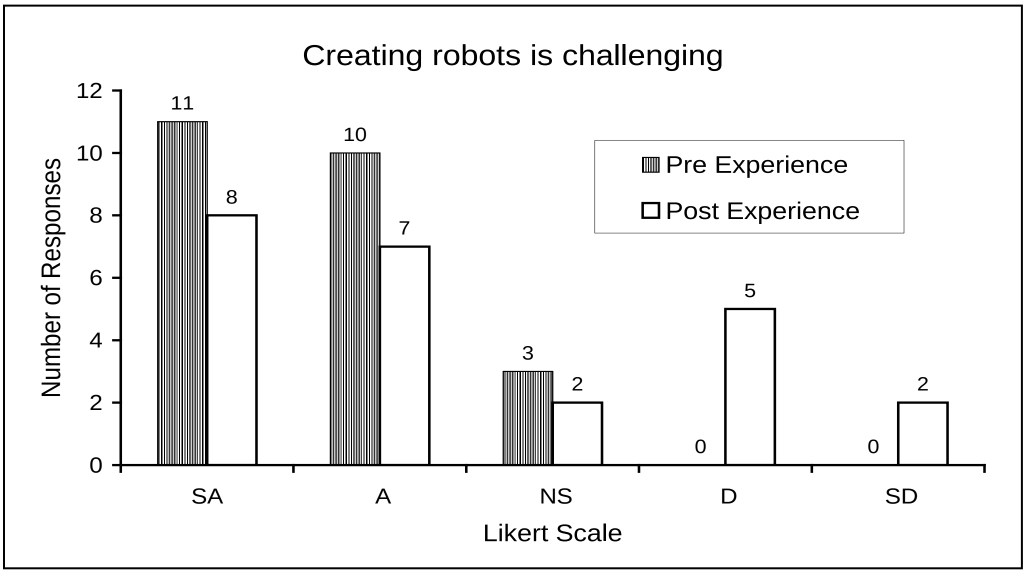

Figure 6.9 Comparison of responses to Item 11 on Pre- and Post-Likert Scale Questionnaire about the challenge of creating robots.

There was a noticeable move from the affirmative to the negative in this question, with seven now disagreeing with the statement in the post-experience questionnaire. While 21 out of 24 students agreed that the experience would be challenging in the pre-experience questionnaire only 15 students now possessed a reflective mental model indicating that the creation of robots is a challenge. Ellen, Jayne, and Sam had not altered their agreement espoused mental model, but Bree now found the creation of robots unchallenging whereas, before, she was uncertain. Bree's reflective mental model was probably influenced by her belief in her success indicated earlier. This success, Bree attributed to both Pamela's teaching "about robots" and also having the opportunity to experience making and programming robots with a partner. She also found her experiences were successful because she "read the instructions". These examples indicate that she was able to use various strategies to experience success.

The mental model of a challenging task and how appropriately the challenge is constructed or presented to students may determine the confidence with which they engage the many mental models that are required to solve or complete that activity. Quite possibly, the students' also held different mental models of what constitutes a "challenge". However, even if the students did hold different mental models, none had had prior robotic experience, thus, the challenge was valid.

Success at challenges may be attributed to the efficiency with which working memory can be maximised by retrieving the appropriate mental models and chunking (Miller, 1956) the information contained within them in order to test and compare possible solutions (Anderson et al., 1996; Henderson & Tallman, 2006; Jeffs, 2004). The efficiency of working memory is enhanced by the implementation of suitable strategies that have been taught and practiced in order that the required mental models for the task can be retrieved from long-term memory and used in working memory (Anderson et al., 1996; Halford, 1993). The responses in the Likert Scale Questionnaire by the students indicate that they were able to make more efficient use of their working memory to meet the challenge of robot construction and programming than they had predicted in their espoused mental models. Either, their reflective mental models were enabling them to be reflective learners who were more aware of the degree of success of their engagement with the domain, or the success they had experienced diminished the magnitude of the challenge of robotics itself.

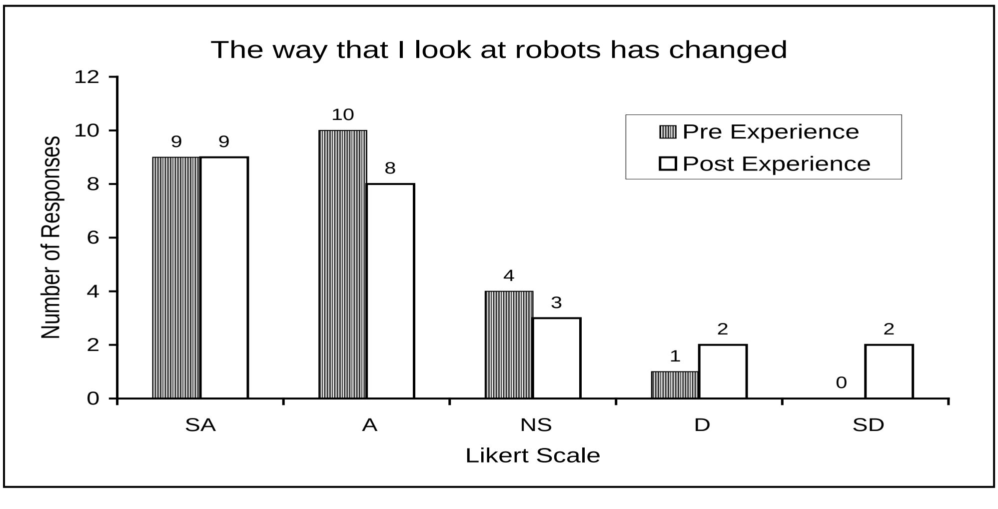

Figure 6.10 Comparison of responses to Item 14 on Pre- and Post-Likert Scale Questionnaire about changes in the way the students look at robots.

The promotion of metacognitive strategies was a key goal of Pamela’s pedagogical practice and a Pre/Post question aimed to determine the students’ understanding of learning, thereby targeted their metacognition (Figure 6.10. previous page).

They had been required to make a prediction in the pre-experience questionnaire that forced them to consider how active learning might alter their perceptions and knowledge (Newton, 1996) about robotics. The reflection required the students to respond with conscious consideration about the way in which they had incorporated new learning into their mental models of robotics: their metacognitive processes and how they are used to gauge the learning distance travelled.

The responses in Figure 6.10 demonstrate that three more children believed that their perception of robotics had not changed. This may indicate that they believed that their mental models may not have incorporated new concepts and knowledge. In other words, they may not have experienced “real learning” (Stripling, 1995, p. 165), if they had not restructured those mental models to incorporate such experiences. While all of the interview participants agreed that the way they looked at robots had changed after the experiences, only two, Ellen and Jayne, had made this prediction in the pre-experience questionnaire. This indicates that these two were aware of the substantive learning experience they were about to undertake and that it would impact their perception, that is, their mental models of robotics.

In conclusion, four of Pamela’s reflective mental models on the success of the project were reflected by the students: the use of metacognitive strategies; perseverance as a group member; perception of the challenge of robots; and the recognition of the learning journey. This match may indicate that her pedagogical practice of encouraging independence in problem-solving was being communicated well to them. This effective communication between Pamela and her students enabled them to make links to the self-knowledge contained in their individual mental models.

Making Mistakes and Problem-Solving

Mental models provide a basis from which students can rationalise or explain their application of problem-solving strategies (Bibby, 1992) and their success in correcting mistakes is of vital concern to educators who are structuring learning programs and associated assessment strategies. The students faced many problem-solving challenges when constructing the robots and programming them for action. Data were collected about how they used strategies in such situations.

It was expected that the students had been using a variety of mental models to negotiate unique situations in a new domain. They were moving from being novices with the equipment to various levels of expertise as they travelled forward on their learning journey. While their espoused mental models would facilitate certain levels of problem-solving capability, it was expected that, as their experience grew, they would be engaging more expert mental models in a more productive manner. Various mental models would be enabling them to operate within the robotics domain even if their conception of such a domain was incomplete or incorrect (Norman, 1988; Williamson, 1999). Through their constant running, such mental models would be incorporating understandings and knowledge from the encounters with the domain (Henderson & Tallman, 2006) and the students' subsequent performance could be explained by the quality of the mental models they had engaged and constructed (Gott, Benett & Gillet, 1988; Senge, 1992).

The approaches used to solve problems were expected to progress from a formulaic application of skills (Barker, van Schaik, Hudson, et al., 1998; Henderson & Tallman, 2006; Senge, 1992) to mirror more closely those of an expert, where a greater majority would be making more appropriate, possibly creative, responses to unpredictable situations (Sloboda ,1996). It was expected that they would be relying less on help from others as their first option when facing an unpredictable situation and more on their own mental models to solve a problem.

Teacher.

Pamela observed a fundamental difference between how the 52 students solved the problems they encountered with the robotics equipment and how she approached the same issues. She believed that "they [the students] look at things from a different point of view" compared with the sequential, procedural way in which she approached the activities. There were also differences among the children themselves. Some approached the tasks and "jumped all over the place" while others followed through the process step-by-step in a similar way to Pamela's sequential progression. Pamela observed the students beginning to understand her maxims, for example, "frustration is a part of problem-solving" and "we all don't think alike".

Pamela was, as Stripling (1995) argued, attempting to help the students to identify what mental models they were using for problem-solving by encouraging them to review their strategies and identify what information they had used and what was needed in order for a problem to be overcome. Pamela demonstrated her effort to understand the mental models with which her students were functioning within the robotics domain.

Pamela's pedagogical mental models influenced her creation of a self-directed learning experience in which the students had to "problem-solve themselves with as little interference" from her as possible. She worked hard to address their habituated mental model of "putting their hand up every time something goes wrong and every time they've got a problem" by encouraging them to go back over what they had done to find where they had made an error. She refused to give answers and "they weren't very happy about it to start off with". In fact, one student became quite annoyed and stated, "Well, you're supposed to be there to help us!" (Pamela, Post-Experience Interview, 5 September 2005). Pamela found that her social constructivist strategy eventually proved successful in encouraging independence as, "once they'd actually succeeded the first time by themselves, there was less of it" and, by the end, they were sourcing help from the program, their own experience, and sometimes other "expert" children. She found that most students accessed "different people for information that is something they don't normally do" and that the experts who arose from the groups were "quite happy to help and give instructions" (Pamela, Post-Experience Interview, 5 September 2005) in the role of a more capable other (Vygotsky, 1978).

The need for instructional remediation, such as that required for major errors in construction or programming, occurred infrequently and most problems students encountered could be solved by guiding them to read the construction books or the information section of the program. The students' annoyance at Pamela's apparent lack of alacrity in providing direct assistance faded (Piaget, 1970) over time and, while she initially provided lots of "pointing them in the right direction", she found that they discovered that there was useful information that they could access themselves.

Overall she realised that, for all the students,

> their problem-solving has changed. The way they approach problems has changed. The fact that they actually access each other now! They think differently about how to solve a problem. I think that it's a direct result of their experience. Their ability to track through things, one step at a time has improved. Their concentration has improved (Pamela, Post-Experience Interview, 5 September 2005).

Pamela's reflective mental model held that the students had more robust mental models of problem-solving because they now held firm self-belief in their ability to do a task. This was a "big shift" from the way in which they approached problems prior to the robotics experience. She further asserted that the students had developed new understandings of the method by which they could solve problems and this was "an active mental process by the learner to put new information into a context, framework, or mental model" (Stripling, 1995, p. 163). Stripling (1995) added that, if the subsequent mental model is flexible in its adaptability to other situations, then it will survive. What is of primary interest is whether the students held similar reflective mental models of their personal problem-solving capacity through the effective running of their mental models. Did they match or mismatch those held by Pamela?

How students extract the information, from the world or in their head (Cronje & Fouche, 2008; Norman, 1988; di Sessa, 1986), that they will require to solve a problem, may depend on sourcing internal mental models that they perceive to be of use and information from the environment that will assist them to reach a goal (Goodwin & Johnson-Laird, 2008; O'Malley & Draper, 1992). Effective problem-solving thus relies implicitly on being good at finding information, much like a robust search engine will use the keywords we give it to find the most suitable websites. Once the information needed has been found, the appropriate mental models with which to manipulate it will be retrieved and run.

Students..

The students were asked to make predictions (Pre) and reflect (Post) on their mental models of problem-solving in the Pre- and Post-Experience Likert Scale Questionnaires. Engaging problem-solving strategies often necessitates experimentation at searching for information and the filtering of that information for trial solutions to the problem at hand. The students' responses to statements, about how their learning was enhanced by such opportunities, can indicate their degree of success at engaging various strategies to solve problems. Item 28 asked the students to consider: "I am more confident when I have the chance to correct my mistakes", and the results did not vary between the two data collection periods with 17 strongly agreeing and seven agreeing. None of the students doubted that confidence in learning comes from having opportunities to find out where they made errors.

These results were replicated when the students were asked to reveal more information contained in their mental models of problem-solving by considering Item 29 (Figure 6.11).

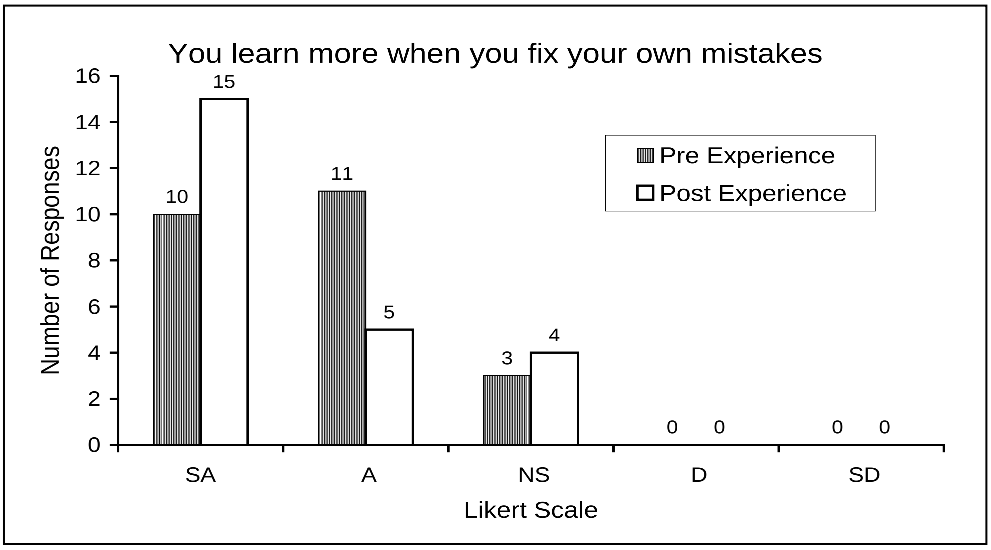

Figure 6.11 Comparison of responses to Item 29 on Pre- and Post-Likert Scale Questionnaire about learning more when given the opportunity to fix their own mistakes.

There is a clear Pre to Post shift to the strongly agree response with five more children now responding. Six fewer children agree and one more student is unsure of the efficacy of fixing your own mistakes (Figure 6.11). The majority of the students still believed that they learned more from fixing the mistakes they had made. Haycock and Fowler (1996) proposed that mental models are a “convenient mechanism with which to consider how we acquire knowledge, achieve understanding and generalise problem-solving skills to make them available to different situations”(p. 28). The act of fixing one’s own mistakes is clearly a strategy that could be embedded effectively by 20 students and tentatively by four in their mental model for problem-solving, allowing 20 to perceive themselves as independent learners able to access effective problem-solving strategies.

The reflective mental models of effective problem-solving and how fixing mistakes enhances learning were also explored in the interviews where the four students provided strong links between problem-solving to fix mistakes and how much was learned. Table 6.5 below provides the relevant comments to questions (Appendix K).

Table 6.5: Student responses about problem-solving effectiveness.

Student	Responses to questions about problem solving and learning
Bree	I would go back through the steps to see where I missed out. I learned it on my own.

Student	Responses to questions about problem solving and learning
Ellen	You need to know what you've done wrong to learn from it. If you couldn't problem solve, you'd probably be stuck on the first one if you did something wrong. You can't really expect everything to go right.
Jayne	It was good to do something else again because you know what to do; you know how to sort it out.
Sam	Sometimes you have difficulties and sometimes the program doesn't always work out and you just try it again and then, if it still doesn't work, then try something different. Sometimes you've got to try again and again. I suppose we're learning something [grudgingly acknowledged].

Metacognitive strategies engaging the two problem-solving strategies, going back over the steps and trying something different, had been introduced by Pamela at the beginning of the students' experiences. These had been incorporated into their reflective mental models of effective problem-solving (Table 6.5). The students were successfully employing metacognitive strategies either consciously or unconsciously. This use of metacognition would have enabled the students to understand that they, in fact, did not understand a particular process or concept but that they could retrieve and use mental models of effective problem-solving to enhance both their information-gathering skills and the subsequent accuracy of solutions to their investigative efforts (Henderson & Tallman, 2006).

Strategies that were useful to the students in overcoming hurdles in programming and construction were evident in their responses to items in the Likert Scale Questionnaires about their problem-solving planning strategies. Item 30 on the questionnaire asked them to consider the statement: "I can solve problems by thinking about them and planning what to do". There was very little variation in their responses from the initial pre-experience questionnaire where a predominantly positive response (N=20/24) was shown. But, in terms of individual learners, twenty of the twenty-four is quite a positive result and indicates that little had happened in the robotics activity to negatively impact on their perception of success.

To clarify their mental models of their efficacy at problem-solving, an additional question was added to the post-experience questionnaire (Table 6.6).

Table 6.6: Student responses about solving problems.

Question 35: I was able to solve the problems I had with the robots.					
	Strongly Agree	Agree	Unsure	Disagree	Strongly Disagree
Responses	9	11	3	1	0

Most of the students (N=20/24 in Table 6.6) found that they were able to engage problem-solving strategies when they encountered difficulties with programming and construction. Jayne was the only interview participant who expressed some uncertainty with this statement and, although she found that engaging problem-solving strategies "started to get me somewhere", she relied very heavily on other students or the teacher to "show me" (Jayne, Post-Experience Interview, 5 September 2005) thereby signalling a salient message to teachers. While she also acknowledged that using problem-solving strategies enabled her to learn more, she felt that on many occasions she was unsuccessful in completing the tasks she set out to accomplish and recorded in her journal. Jayne was working with mental models that were not as malleable as they could be to accommodate new understandings (Williamson, 1999; also Chapter 5).

It was indisputable that students felt various levels of frustration when they encountered problems during the robotic activities (Chapter 5). Item 39 was an additional question on the Post-Experience Likert Scale Questionnaire and sought students' attitudes to the frustration (Table 6.7).

Table 6.7: Student responses about frustration felt when encountering problems.

Question 39: I found it frustrating when I couldn't solve a problem with the robots.					
	Strongly Agree	Agree	Unsure	Disagree	Strongly Disagree
Responses	9	8	2	4	1

The data shows that the majority of students (N=17/24) experienced some level of frustration when encountering problems that, from a constructivist perspective (Jonassen, 1995), should have encouraged them to engage more diverse and complex mental models as they endeavoured to solve problems. This activation of a variety of mental models to solve construction and programming errors exemplify their “dynamism” (Bibby, 1992, p. 168) and indicate how mental models provide, in themselves, a useful basis from which students can rationalise the effectiveness of the strategies used.

Bree responded in the strongly agreed category while Ellen and Jayne agreed. The Post-Experience, Semi-Structured Interviews on 5 and 6 September 2005 revealed more detail. Bree felt most frustration when attempting to “find pieces” for constructing the robot and when working with other students with whom she was paired. Her “frustrations” were, therefore, quite specific. She was pragmatic about the programming or construction problems she encountered and effectively ran her mental models for problem-solving in those areas. Ellen, while feeling frustration with her personal inability to solve some construction problems, firmly believed that Pamela’s practice of not providing specific solutions helped the students to learn. Jayne agreed with Ellen’s view of Pamela’s pedagogical methodology but dealt with her frustration when encountering errors by continuing to ask others, students or the teacher, and then “sorting it out for yourself”.

Sam disagreed that he felt any frustration at the lack of problem-solving success. This indicates his reflective mental model contained less of a focus on success at certain stages in comparison with the mental models of other students. He saw problem-solving experiences as an opportunity to “find out what the problem was” and, although he found the process of finding his own solutions a “waste of time” when the teacher “could easily just tell us”, he was more concerned with wasting valuable hands-on time than with not being successful at any particular point. Sam was interested in, as Johnson-Laird (1983) so eloquently said, “what causes phenomenon, what results from it, how to influence, control, initiate, or prevent it, how it relates to other states of affairs or how it resembles them, how to predict its onset and course, [and] what its internal or underlying ‘structure’ is” (p. 2). Sam was eager to be “on” the learning journey so he could actively engage with the robots and use his mental models to facilitate the investigation of alternatives when programming and constructing and to solve problems he encountered in these areas (Carley & Palmquist, 1992; Goodwin & Johnson-Laird, 2008; Renk et al., 1994). He experienced frustration with any delay in moving forward on this journey.

Pamela did create disequilibrium (Piaget, 1970) or perturbation (Ritchie et al., 1997) within the students' mental models of problem-solving when she failed to perform in the "helpful" ways to which they had become accustomed. Item 38 on the Post-Experience Likert Scale Questionnaire asked the students to consider the statement: "I received helpful guidance from the teacher when I had a problem" (Appendix G). All but three of the 24 students now held mental models of guidance for problem-solving that placed Pamela's strategy in the useful category. Sam was one of the two students who responded in the strongly disagree category of the item. Jayne was the only student who was unsure if the guidance was helpful and both Ellen and Bree strongly agreed that Pamela's guidance was helpful in a problem situation indicated by Bree's interview comments "she helps me with clues" (Table 6.8). Ellen and Bree's mental models indicated that they had been able to reconcile any perturbations felt with the enactment of mental models that would instantiate effective strategies to solve the problems they encountered. These wide ranging responses are more indicative of the individual reflective mental models with which the students were now operating than any deficiency in Pamela's pedagogical practice.

The four students interviewed in the Post-Experience Semi-Structured Interview clarified their mental models of sources of help (Table 6.8).

Table 6.8: Student responses about receiving guidance from the teacher.

Student	Responses to questions about sources of help
Bree	The teacher is always there if you need some help. She helps me with clues. Or other kids. I would just look on the internet or read it in books. I just sit down and try and figure it out myself.
Ellen	Get the instruction manual and look really hard at it. First, you'd ask your buddy [partner] or a friend and if they didn't know, you'd probably try to figure it out yourself and, if you still couldn't do it, you'd probably ask the teacher for some help.
Jayne	I'd look in the magazine [constructopedia] or on the computer as it shows a picture of what the robot's meant to look like. Ask the teacher because she knows a lot about robotics, because she's helpful, and you could ask other children in the group as well.

Sam	You could look on the help thing on the system or you could look in the book. I asked the teacher what to do and she told me to go to the help menu. She wanted us to do it for ourselves because you're going to need that when you grow up. You aren't always going to have a teacher there.

All students mentioned similar strategies for sourcing the help they need to overcome problems. The two students who strongly agreed on the Likert Scale Questionnaire, Bree and Ellen, voiced mental models that included themselves as a source of help indicating they believed in taking ownership of their learning. All students included the teacher. Bree provided Pamela as the primary source of help but Ellen and Jayne both saw the book or manual as the primary source. Sam's first point of assistance was the computer information or help function, a source that he had first been introduced to during the Stimulated Recall data collection episode in July (Chapter 5). Sam's mental model now held a rationale for Pamela's strategy. Both Pamela and the manual [book or constructopedia] are included by all four students' indicating matching mental models of sources of effective help. The computer [help function] and other students or partners are the next most useful for all students with three students proposing them as effective sources of help. Relying on their personal resources was part of Bree and Ellen's mental models. This indicates that, while confidence in problem-solving in this domain was increasing, it had not reached a point that demonstrates more expert capabilities for all four students.

Results of investigations into problem-solving mental models indicate that, while the student participants have used a variety to facilitate the use of strategies, their perceptions of the usefulness of those strategies to enable them to learn show some matches. Some mismatches, particularly in the order in which help is sourced, indicate idiosyncratic and individualised (Henderson & Tallman, 2006; Norman, 1983) mental models of the students in problem-solving and the sources of help that guided them through the difficulties they encountered.

In Summary

One of the most salient responses to the theory of mental models was offered by Preece et al. (1994) who proposed that mental models account "for the more dynamic aspects of cognitive activity" (p. 130). This simple pseudo-definition offers a glimpse at the continual activity that is necessitated by engagement with learning.

Students should leave class each day having experienced the fact of running mental models that enabled them to negotiate learning and social experiences. Observation can enable teachers to glimpse this change in students, as Pamela noted in the Post-Experience, Semi-Structured Interview:

> You get that glimmer at the end where it all just falls into place. Others just plod along quietly and did what they had to do. But [in] all of them you could see a reaction, a very physical reaction [e.g., a smile] when it all came together (Pamela, Post-Experience Interview, 5 September 2005).

This physical reaction was also evident as Bilbo Baggins continued his journey, using his mental models to negotiate with rather different characters to the ones with whom the students in this study were negotiating.

> Somehow the killing of the giant spider, all alone by himself in the dark without the help of the wizard or the dwarves or of anyone else, made a great difference to Mr Baggins. He felt a different person, and much fiercer and bolder (Tolkien, 1937, p. 146).

The students, in this study, were also bolder because of using their mental models to negotiate a challenging environment.

CHAPTER SEVEN: *Teach-Back and Focus Group*

> There were many paths that led up into those mountains, and many passes over them. But most of the paths were cheats and deceptions and led nowhere or to bad ends; and most of the passes were infested by evil things and dreadful dangers. The dwarves and the hobbit, helped by the wise advice of Elrond and the knowledge and memory of Gandalf, took the right road to the right pass (Tolkien, 1937, p. 53).

Introduction

The successful completion of Bilbo's journey was measured, not only by the fact of his survival, but also by his choice of the correct pathway that would lead to vast wealth for the journeymen. Bilbo could not have successfully undertaken this journey alone and nor could he, from his limited interactions with the world, have negotiated a pathway through the dangerous situations in which he was placed without the guidance of Gandalf. Similarly, the robotics journey undertaken by the student participants could not have been undertaken alone or without guidance from a teacher who had experience and knowledge of learning within a technology domain.

The students in this study had the opportunity to both design and create artefacts: robots. The processes of designing and creating enabled them to concretise and personalize the formal processes of learning because the interactions with those artefacts, within the environment, created and activated individual mental models. Learning through problems-solving is too often treated as an obstacle to overcome rather than a journey for the individual. Cognitive pathways for such a journey can be expanded by inspired educators. This chapter follows four students as they were confronted with situations that challenged their individual mental models of teaching, learning, and assessment.

Teach-Back

Teach-back provides the opportunity for participants to demonstrate their procedural (van der Veer, 1990), conceptual (Barker, van Schaik, Hudson, et al., 1998), and reflective (Jonassen, 1995) knowledge within a domain (Chapter 3). At the post-experience stage of the project, it would be expected that the participants have acquired the satisfactory understanding of the system necessary to teach another student (Jonassen, 1995) enough about the system, and its components, so that the neophyte student could perform a predetermined, introductory task. The teach-back episodes were conducted on 20 October, 2005, one month after the post-experience, semi-structured interviews. At this point, the students had been working with the robotics equipment for seven months and it had been determined by the researcher, through observation and analysis of their journal entries, that they had acquired a level of competence with the domain suitable for this method of data collection.

Teach-back methods for data collection usually require the participants to describe on paper how a system operates (Barker, van Schaik & Hudson, 1998). In this study, the researcher decided that the student participants would teach another student using the actual robotic materials.

Mental Models of Teaching and Learning

It was anticipated that the project participants would be able to teach their pupils enough about the system to enable the pupil to perform a simple construction and programming activity in one half-hour, focussed instruction period. It was expected that when they taught their chosen activity, they would use their own language, terminology, and processes in a suitable mode of teaching based on how they felt their pupil would best “learn” the necessary skills and knowledge. Snow (1989) recognised that teaching and learning involved a progression from simple mental models to more complex mental models within a domain. Therefore, to foster students’ instantiation of this logical progression in the teach-back episodes, the selection of teaching mode was left entirely to them. The students were not taught an “effective” way to teach or given any suggestions apart from the general instructions provided (Appendix V). How each student created the instructional task should reflect their personal learning strategies (Snow, 1989), thereby providing evidence of their mental models of both teaching and learning.

Preparation: Designing the Teaching Tasks

Each of the four student participants was advised, one week in advance, that they were required to create a lesson — to build and program a robot for a simple task — for their pupil that would last for 30 minutes. Students were advised that the objective of the lesson was for their pupil to gain confidence to complete this hands-on activity unaided. Teaching strategies, that would facilitate this objective, were not discussed. It was predicted that the students would spend time thinking about their forthcoming lesson and be running multiple mental models that would consist of the mental images, analogies, propositions, and the conceptual, declarative, and procedural knowledge (Johnson-Laird, 1983; Redish, 1994) that was associated with learning about robotics. While there may be predictable commonalities in their approach to teaching, due to shared experiences, each of the students would be running individual yet functional mental models (Norman, 1983) to investigate the alternatives for tasks and processes as they explored the new, real world of teaching (Carley & Palmquist, 1992; Renk et al., 1994).

The individuals to be taught, the novice pupils, were the same age as their new teachers and were selected anonymously from students who had no robotics experience. This selection was based on face-down piles of names put into two piles based on gender. It was decided to keep homogenous gender groups for the teach-back episodes as there were no research parameters to differentiate gender included in this research. Selection of participants met the ethical requirements of the study as the consent forms (Appendix B) signed before the commencement of the project included all anticipated research methodologies and data collection tools including photographs and video and audio taping.

The eight students were given specific instructions immediately prior to the commencement of the teach-back episode (Appendix V). This instructional set provided further clarity about the teaching/learning situation and the roles each person in the room would be adopting. An audio cassette tape recorded all interactions in the episodes, including this introduction. While other data collection episodes had been video-taped (stimulated recall interviews: Chapter 5), it was decided that still photographs would be taken of the participants and voice recording and observational notes would be conducted by the researcher. Video evidence is very powerful and provides valuable evidence of the nuances of interactions. Here, the students were undertaking a challenging, new role as a teacher and the added pressure of a camera that recorded all of their actions could prove to be intrusive and was, in this case, unnecessary. Another teacher, not associated with the project, was in the room at the time to monitor the audio cassette recorder, but had their back to the students and did not interact with or watch any of the participants.

Teaching Robotics

The four student participants, Bree, Ellen, Jayne, and Sam, each taught another student their selected task for a period of 30 minutes. The photographs

(Figure 7.1) capture the students, who selected pseudonyms, engaged in a variety of activities including the construction of the robot and programming of the computer software.

Figure 7.1 Students engaged in Teach-back episodes, 2005.
Clockwise from top left corner: Bree and Belinda, Ellen and Eliza, Sam and Axel, Jayne and Mary. (Parental permission given for inclusion).

After the students had taught their pupil for 30 minutes, the expert teacher was asked to leave the room, and a brief interview of the novice pupil was held. This requirement, to ensure that the learner gained confidence in robotics as a result of the lesson, had been communicated to the expert teachers one week before the lesson was to be held (Appendix V). The novice pupils were asked about their confidence to repeat the activity alone as well as what percentage of success they would predict for the completion of the task. They were then asked to explain why they felt they held that level of confidence to support their numerical quantifier. After these five-minute probes, each was thanked for their time and involvement and asked to return to their classroom so that the students who had taught them could be interviewed.

A ten minute interview (Appendix V) was then held with each expert teacher to discover the reasons for the selection of their teaching methodology and how confident they were that those strategies facilitated effective learning by their pupil. This probe provided data that would reveal how much of the teaching/learning process was personalised (Snow, 1989) and therefore indicative of the student's mental models of teaching and learning. This study's use of teach-back with middle years students undertaking a robotics experience allowed a comprehensive view of the mental models of teaching and learning with which they were operating.

Data Analysis

The data collected from these episodes were coded for a variety of mental models including procedural knowledge [PRO], conceptual knowledge [CON], predictions of success [PRE], pedagogy [PED], cognitive processes [CP], and assessment [ASS] (Appendix M for full list of codes). The last three codes had only been previously used in the teacher's interviews. The students required the experience of organising and conducting an authentic teaching episode, such as that in teach-back, before they would be able to exteriorise relevant pedagogical mental models. Some of the pre-episodic questions this researcher posed for herself in her research journal included: Would the student participants engage their own personal learning strategies to teach (Snow, 1989)? Would the student participants engage multiple strategies (Kyllonen et al., 1984; Siegler, 1989), such as those used by their teacher to ensure their fellow pupil had the best opportunity to learn? It was anticipated that they may have some advantage over their teacher in this peer-teaching role because their semiotic and semantic language could have a closer match to that used by their pupils.

Teach-Back Episode

On the day of the episode in October 2005, the four participant 'expert' teachers, were given five minutes to organise the teaching episode they would conduct with their learner before they were required to commence the lesson. It was anticipated that they had given some thought as to what they would teach due to the one week's notice they had been given. The time limit of five minutes for organising equipment may have been a constraint if they had not been prepared beforehand. The expert teachers were asked if they were ready to commence at the end of the five minute preparation time and none required further time to organise the teaching space, the materials, their lesson, or themselves.

Instructions had been given to all participants (Appendix V) and they were asked if they understood. The novice pupils were not required to leave the room when the materials were being prepared, but were dissuaded from any interaction with the expert teacher until the lesson was ready to proceed. The novice pupils were in a new environment (robotic laboratory) with equipment (robot kits) they had not seen or used before and in an activity that they had not yet experienced (research data collection episode, robotic construction and programming). This five-minute period was seen as a time for them to become accustomed to the setting, the equipment, and the experience.

Once the expert teacher was ready, the audio tape recording device was turned on and the lesson commenced. Observational notes were taken of the lesson and the participants' somatic interactions were recorded in the notes. These notes supplemented the transcript from the tape as they described what the students were doing during the lesson. As an example, one of the descriptions in the notes stated, *Jayne boots up the computer and has her hand on the mouse.* This type of observation enabled a picture to be created of what was happening and gave the transcript much more detail. At the end of the thirty minute period allowed for the lesson, the participants were asked to stop and the short interviews proceeded.

Participants were interviewed separately. Each novice pupil was asked about the confidence they had to engage with the robotics kit on their own and the percentage of the success they might have. They were thanked for their efforts and asked to return to their classroom. Next, the expert teacher was asked how confident they felt that they had covered the required experiences to enable their learner to work independently on a task with the robotics kit. Other questions posed to each student teacher (Appendix V) included their reason for selecting the chosen teaching strategy and whether this matched the way in which they had been taught. Depending on their responses to these questions, further investigations were made as to their mental models of the efficacy of the teaching strategies and how these may have promoted active learning by their learner. Participants were asked if they would alter their teaching method if they had the opportunity to teach robotics to another pupil and, if so, why they would make those changes. They were being asked to reflect on their pedagogy because they now had a very specific experience from which to draw.

Mental Models of Teaching Strategies

The responses to the questions about the students' chosen teaching strategy revealed that they had various mental models of teaching (Table 7.1).

Table 7.1: Observed teaching methods. Students' reasons for selecting those methods and preferred learning style.

Student	Observed teaching methods	Reason for teaching methods *	Preferred learning style *
Bree	Guided. Pupil had total hands-on experience. Sequential steps explained.	That's the way Pamela taught us. So she [the novice] could figure it out for herself.	By doing it yourself. If I make mistakes the teacher is there to help.
Ellen	Guided. Pupil had total hands-on experience. Sequential steps explained.	It was because that was how I learnt to do it.	Build our robot and then go on to the programming. Having a robot built before you actually started it [the programming] made it easier than having the computer at one screen [showing what the robot should look like]. [Then] you take forever to build it.
Jayne	Demonstrated. Pupil had minimal hands-on experience. Some sequential steps not included. Some sequential steps explained.	So she could see what buttons to press and how to get into it and what it does on the computer. She didn't click on the computer because I was teaching. I did it because she wouldn't know what to do.	Doing it by computer and by looking through all of the steps because it tells you what to do.
Sam	Demonstrated. Pupil had minimal hands-on experience. Sequential steps not explained.	I thought it was easiest for both of us. I guess I was experimenting a bit.	Like just now. Not giving people the big tasks.

Note: * Response to Interview questions.

Bree and Ellen taught the way they had been taught. They gave control of the materials to their pupils while they guided them through the sequential steps of building and programming the robot. By chosing this method, Bree indicated her belief in social constructive learning. When asked if they felt confident that this had been a useful teaching method, they each agreed that it was and they would not change their methodology. Bree believed you learned best by using "your own hands" while Ellen based her way of teaching on how she had learned.

Jayne and Sam did not teach the way they had been taught. They demonstrated the building and programming process and gave their pupils little opportunity to have hands-on experience. When asked if she would alter her methodology in any subsequent teaching episode, Jayne believed that she would show more things next time, such as: how to plug in the infra-red (IR), use the instruction booklet, and use the robotics kit. Sam responded by saying that his pupil should, probably, have had more opportunity to handle the equipment. While acknowledging that he taught in a different manner to that which he had been taught, he thought that his method was easier for him because he “didn’t have to go through and explain everything” to his pupil. Both Jayne’s and Sam’s mental models portrayed themselves as experts who had all of the “knowledge in their heads” (Norman, 1988; Jonassen & Henning, 1999) and excluded their pupils from the experience of constructing their own knowledge through a hands-on experience.

Bree and Ellen’s pedagogy was synchronous with the pedagogical philosophy and applied practice of their teacher, Pamela, whose mental model of teaching and learning was based on the collaborative cognitive approaches of constructivism (Derry, 1996; Duffy & Jonassen, 1992; Herrington, et al., 2006; Moshman, 1982; Piaget, 1970; von Glaserfeld, 1995) and social-constructivism (Brown, 1993; Smagorinsky & O’Donnell-Allen, 2000; Vygotsky, 1978). Pamela’s social-constructivist pedagogical approach involved an intentional focus on the development of the independent problem solving-skills necessary to solve challenging building and programming tasks (Chapters 5 and 6). Jayne and Sam’s pedagogical practice was at variance with Pamela’s approach and reflected a behaviourist philosophy (Skinner, 1984).

Jayne taught her pupil the way she approached the robotic programs. Remembering facts and following recipes had been a successful strategy for her in her classroom work (see Chapter 4). Jayne’s responses to interview questions about her teaching approach included a justification that her pupil, Mary would “not know what to do” so she did it for her. Jayne’s mental model of teaching included the belief that Mary “didn’t click on the computer because I was teaching”, so her role of expert required her to demonstrate what was to be done. She continued to focus on a mental model of retention of declarative and procedural knowledge that was evident in her own interactions with the robotics equipment.

The successful construction and programming of the robot was not a criteria of success communicated to the students. In Jayne's teach-back lesson, the robot failed to complete the action it had been programmed to undertake, and moved in the opposite direction. Faced with an obvious error, Jayne continued to run unhelpful mental models and so failed to seek information from other obtainable sources (e.g., the help function, Chapter 5) to find the way around the problems. Even when her pupil, Mary, pointed out that the robot was not going in the direction that they had programmed it to move, Jayne decided to "leave it there and see the next thing"! This indicated that she had few effective problem-solving mental models to guide her through the troubleshooting process.

Sam's mental model included the belief that it was "easier for both of us" to provide all relevant information before any possible problems arose; this did not happen because the robot was programmed successfully during his teach-back episode. However, his pupil, Axel, had 13 questions — such as, how long the robot would run and why only one wheel was working — that were left unanswered throughout the lesson. While Sam avoided answering these questions, he did show Axel how many different programs the robot could hold and how many of the components worked. He talked a lot to himself during the episode and treated Axel as an audience member rather than an involved and motivated pupil.

Bree and Ellen managed their mental models of teaching using various functions to diagnose their pupils' actions, plan procedures to explain, and recall terminology to communicate. They guided the learning through their teaching. Jayne and Sam were managed by their mental models of teaching and focussed on demonstrating the procedures without engaging their pupils in a hands-on exploration of the kit.

Mental Models of Learning and Teaching Strategies

The teach-back episodes also provided an opportunity for the "expert" student participants to run their mental models of learning with robotics enabling them to test the possible outcomes of their chosen teaching style/pedagogy. As Cohen et al. (1995) reported, as an individual is working through a problem-solving situation, in this case how to teach, they are running mental models for both the plan of what to do and the sequential actions required to accomplish that plan.

Social constructivist pedagogical practice requires time, as the full year of robotics demonstrated. Therefore, the novice pupils' percentages of confidence to undertake robotics are interesting. While Bree and Ellen's pupils gave confidence percentages of 40% and 60% respectively, Jayne and Sam's pupils gave much higher responses of 70% and 75%. The novice pupils, who were selected for the teach-back episodes, had no prior experience with the domain and also had various levels of problem-solving skills, so it is not possible to make an accurate comparison of their responses as to the effectiveness of the teaching conducted by the students from their novices' perspective due to these differences. They may have been expressing greater confidence in their teacher than they were in themselves! Bree, Jayne, and Sam were all confident that they had taught their pupils well and that the pupils should be able to work unassisted with the equipment. When asked she responded "Because it was the first time I taught somebody else. And I didn't really know what to do". Thus, Ellen was the only "expert" teacher who did not have confidence in the outcome of her teaching episode.

An interesting comparison is the one between the expert teachers' preferred method of learning and their chosen pedagogical strategy. Table 7.1 illustrates the participants' chosen teaching method for the teach-back episodes and their preferred style of learning. The previous data in Table 7.1 demonstrates that Bree and Ellen had matching mental models of teaching and learning, indicated by the congruence between the teaching method they chose to use and their preferred learning style. There were mismatches for Jayne and Sam. Jayne's preference was for "doing it" when learning but demonstrating when teaching. Sam's preference was doing robotics in "small tasks", representing a hands-on approach, but teaching by providing minimal opportunity for such an experience.

Teaching is a complex process, even for trained adults, and the students' teaching experiences had been limited to peer tutoring other students after only a week's notice and five minutes preparation time. In this data collection episode, they were being asked to design and teach a lesson to a peer. In order to fulfil this task, they would, as Craik (1943) pointed out, necessarily rely on those mental models of learning that proved safe and/or efficient (Newton, 1996) and were, possibly, unconsciously run (Nelissen & Tomic, 1996) by them in past experiences. Therefore, the teach-back episodes enabled unambiguous exteriorisation of the students' mental models of teaching and learning. The veneer of accomplishment (Hennessy, McCormick & Murphy, 1993) in teaching and learning may develop severe cracks when it is put under the spotlight when we are placed in novel situations that require an unconscious reliance on our mental models. Such was the case in the teach-back episodes.

Any facade at completing challenging tasks would be similarly tested when the students were asked to participate in the next data collection episode, in which they would be required to design an assessment task rather than a teaching and learning one. The next section of this chapter follows the students along a learning pathway through the challenging landscape of assessment.

Focus Group

Data for the study, collected through a variety of methodologies, including semi-structured and stimulated recall interviews, Likert Scale questionnaires, teach-back episodes, and journals, were triangulated to ensure confidence that it was “not simply artefacts of one specific method of collection” (Burns, 2000; p. 419). The focus of the various data collection methods was the individual, and how their mental models matched or mismatched the mental models of others. This is a norm in cognitive psychology (Banks & Millward, 2000). However, the situated-cognitive environment (Brown et al., 1989) of the robotics laboratory and the pairing of students by the teacher facilitated the sharing of mental models in an authentic learning experience throughout the study period. Students were creating, running, and adapting (Rogers et al., 1992) their mental models as they engaged with others and with the robotics system.

The sharing of mental models by the participants during learning experiences can and did explain some similarities in their responses to questions on teaching, learning, and assessment during the data collection episodes (Rouse et al., 1992). “Could these shared mental models, evident in the learning experiences, be replicated in a group data collection situation that involved all four novice student participants?” (Researcher’s Journal, 9 October 2005). A group assessment episode was followed by a focus group interview involving Bree, Ellen, Jayne, and Sam sharing experiences. While different in some ways to the classroom environment, it would include similarities, such as the location, the participants, the robotics kits, and the associated activities. The creation of a similar context (Cannon-Bowers, Salas, & Converse, 1993), but one with a specific assessment focus, should provide an opportunity for the students to reveal their multiple mental models of robotics and assessment.

Mental Models of Assessment

This data collection instrument, conducted on 14 and 15 November, 2005, one month after the Teach-Back, required Bree, Ellen, Jayne, and Sam to both design and complete a different assessment piece. The dual experience equipped them with the experience of activating and/or creating mental models from two points of view: the assessor and the assessed. Each of them designed a 25-minute assessment activity for one of the other three students to complete. They worked in the robotics laboratory where two, twenty-five minute assessment sessions were held, consecutively, in one hour-long period. Five minutes were provided for preparation of materials before each assessment activity commenced. Time limits were imposed to decrease participant fatigue. All interactions were videotaped to provide a record of the activity for the researcher. This artefact was not viewed by any of the participants but it substantiated the activities undertaken for researcher’s referral, and triangulation purposes. The following day, the four participants took part in a focus group interview where the assessment activities held the day before were discussed.

The primary aim of the focus group interview was to have a semi-structured exchange among the students in order to investigate their mental models of assessment and the distributed cognition of those models. Also of interest, was how the students used their reflective mental models of robotics to (a) design an assessment task for others and (b) navigate the programming and construction tasks they were given (Carley & Palmquist, 1992; Renk et al., 1994). The students were now being exposed to a new learning environment in this episode for which they would apply previous knowledge to an unknown situation: assessing and being assessed by a fellow student. Their evolving mental models should guide their interactions and so enable them to evaluate expected events and interpret any unexpected events (Norman, 1983) from both teaching, learning and assessment perspective.

The students were given the broadest possible design brief with which to create their assessment task. This flexible approach to assessment should have encouraged them to engage with the assessment process in the way that best reflected their mental models of both robotics and assessment. Resnick (1989; 1994) discovered that different solutions in programming the robot to accomplish goals were created by his participant students, particularly where the tasks the robots were to accomplish were complex. It was envisaged that the students would include some complex construction and programming tasks as part of their assessment if they had experienced success themselves with complex tasks. The authentic assessment of self-directed learning is a challenge and the get it right/get it wrong paradigm (Papert, 1980) may not provide an accurate picture of the cognitive journey undertaken by students. An opportunity to determine how these students distributed their understanding of assessment may provide valuable information on their shared mental models of learning.

Teacher's Mental Models

Another aspect of the focus group data collection episode was the opportunity to gain information about the teacher's mental models of the students' mental models of assessment. The teacher in the study, Pamela, was aware that the four students were designing an assessment task and of the focus group interview but did not participate in either of these sessions in any way. The students were also made aware that their teacher was not formally involved so that they could distinguish the activity from their classroom learning activities. A discussion with Pamela on 26 November, 2005, subsequent to the data collection would ascertain if the mental models she had of the students' created assessment task matched those of the students.

Preparation: Designing the Assessment Tasks

A discussion with the four students about the assessment brief was held one week prior to the task. This period of preparation or cogitation had been used in the teach-back episodes and was seen as effective. During this discussion, the criteria for the task, including content and the amount of guidance to give, were negotiated with the four students, in order to encourage their sense of ownership and control from an assessor's viewpoint. The only non-negotiable criterion was the time limit for the activity.

The level of task difficulty was discussed and all parties (excluding Pamela) agreed that the task should challenge each of the four students to complete a construction and programming task suitable for a student who has had six months experience with the robotics equipment. A question from Bree, "What if I can't do it?", prompted a discussion about the level of assistance that should be given if they were forced to stop because of an overwhelming task challenge. The assistance that their teacher provided in such situations was raised by Jayne and when Ellen offered, "She would give us clues but not tell us the answer", it was unanimously agreed that minimal guidance, in the form of clues, would be given and that procedural assistance would only be provided if the student reached a point where they could not continue without some help.

At the time when the criteria were decided, the students were unaware of who they would be assessing or who would be designing their assessment task. Their partners for the assessment task (Table 7.2) were to be decided on the day of the activity in order to promote equity through the elimination of any possibility of prior negotiation between partners.

Assessing Robotics

On the day of the assessment task, the students were paired with another student by the anonymous drawing of a name out of a hat. Each pair was changed after the first session so that the students who had been assessed in the first round worked with a different student for their own assessment task. This swapping of partners encouraged a fresh start for each student by focussing on a new affiliation and (hopefully) eliminating any lingering emotions from the previous assessment activity. Once the initial pairs had been decided by the drawing of names, the students who would be assessing in the first round were given five minutes to prepare both the materials and the space for the assessment activity. The two, twenty-five minute sessions were held in the robotics laboratory with the student pairs working near each other but not interacting. The sessions were video-taped. The total time taken for two assessment sessions to be conducted was one hour.

At the end of the assessment sessions the students were brought together as a group. They were advised that they would be interviewed the following day in a group interview and were asked to think about their experiences from an assessor's perspective and from the perspective of the student being assessed. These instructions were given in order to focus the students on their mental models of assessment and learning. This would be the first instance of data collection of mental models of assessment in a formal setting with students. It was expected that they would be considering their years of experience as a learner and their recent practice as a teacher during the teach-back episodes to help interpret their experiences as an assessor.

The students designed assessment tasks that offered a variety in the degree of challenge. Three were activities that had been done previously in robotics and the fourth was completely innovative, offering considerable challenge. Table 7.2 provides the assessment piece designed by each student, their explanation of the relevant design criteria, and Pamela's prediction of its level of difficulty.

Table 7.2: Assessment tasks designed by students and Pamela's prediction.

Student Assessor	*Student Assessed* & Assessment Task	Design criteria	Pamela's Prediction
Bree	*Ellen* Pilot Program 3	Mental challenge. [To see] how well she did this time. All I could think of.	Moderately challenging
Ellen	*Sam* Investigator 1	A bit harder to build than other ones. So they could problem-solve.	Moderately challenging
Jayne	*Bree* Pilot Program 2	Already programmed [in class]. Good challenge. A bit tricky.	Very Easy
Sam	*Jayne* Creative task involving 4 motors	Creativity. Not in the book. Hasn't been tried. Original. Fun. Problem-solving. Unsure of outcome.	Very challenging

Each of the students included the idea of a "challenge" in their criteria. This inclusion indicates that their mental models of robotics were robust enough to incorporate a belief in personal success that, therefore, influenced their design of an activity that would involve some problem-solving opportunities.

A comparison with Pamela's mental model of the task challenge each student created provides information about the relative degree of difficulty included in the design. Before Pamela was advised of the actual assessment task each student had designed and before she had viewed the video of the focus group, she was asked to make a prediction about this degree of difficulty and these forecasts are also shown in Table 7.2.

Pamela believed that “they [the assessing student] would have asked them [the student being assessed] to show hands-on construction and to demonstrate their ability to work through the [software] program”. Pamela’s prediction for both Bree and Ellen accurately reflected the assessment tasks they designed. She believed they accurately rated them. Pamela’s predictions of the assessment tasks designed by each student (Table 7.2) were accurate and the match demonstrated the accuracy of both her mental models of the chosen assessment and the capability level of each student.

Discrepant mental models became apparent when analysing Jayne’s data in Table 7.2. She reasoned that the Pilot Program 2 she selected would be a “good challenge” and a “bit tricky” but Pamela explained that Jayne “sees it as being a creative task but, in actual fact, it’s laid out in the training missions”. Jayne’s mental models of her own constructing and programming experiences were informing her assessment strategy. The lack of competence in robotics that she had previously displayed (Chapter 5 and Teach-back discussion in this chapter) guided her to design an assessment task that she may have found “tricky” but was actually moderately challenging or a “middle of the road one” as rated by Pamela.

When discussing Sam’s assessment piece, that was extremely complex, Pamela noted, “He’s a divergent thinker and he wouldn’t understand that the other person probably doesn’t have the prior knowledge that he does”. When Pamela was advised that Sam had revealed his personal uncertainty as to the validity of the programming tasks he had included, she stated, “It doesn’t surprise me that he set something that was outside his own knowledge base”. It was evident that Sam was using the assessment episode as an opportunity to see what could be done with the robotics equipment and, in some way, to discern whether other students may have had knowledge that he, himself, did not have. His curiosity guided the complex design process that Resnick (1989; 1994) believed became evident when students were provided with the opportunity to accomplish goals without strict parameters and where, in the case of this study, the robotic tasks to be completed were themselves multifarious. While other students reflected over what had been done during the six months of robotics, Sam was considering “what had not been done” to inform his assessment strategy.

The Focus Group Interview: Another Journey into Unknown Territory!

The focus group interview was held in the robotics laboratory on 15 November 2005, 24 hours after the assessment tasks. The four participating students, the interviewer, and one adult who was filming the episode, were present in the room. An introduction was given to the focus group interview (Appendix W (A)) and the students indicated they did not need clarification about what was to take place.

Two questions were asked in quick succession at the conclusion of the researcher's instructions (Appendix W (A)) and, retrospectively, these opening questions could have been delivered more coherently. However, the second of the two questions prompted the students, "How did your thoughts of robotics guide you in deciding what you were going to give as a test?" What followed was, at first, very hesitant attempts to respond to the questions being posed and the first fifteen minutes saw the participants responding individually, without much discussion, to the focus group questions (Appendix W (B)) put to them.

The students were at ease with the interviewer and their hesitancy to be more interactive could not be attributed to reticence about sharing their thoughts with someone unfamiliar. The camera's and other adult's presence were not novel as they had been filmed during stimulated recall episodes in July and during their assessment tasks the day before. However, this interview context was new and it was a novel experience for them to be asked about their views, beliefs, and opinions on robotics when other students were present. Therefore, it took some time for them to adjust to the uniqueness of the focus group situation. This novelty arose from both the opportunity to express and explain their thoughts with others and the requirement to listen carefully to the ideas of other students. Persistence and patience was rewarded and the interactions grew richer, culminating in a "we-ness" or "us" collegiality of shared mental models (Anderson et al., 1996) that was relative to the social context (Bibby, 1992) of the semi-structured exchange.

After the students had responded to general questions about the design of their tasks, they were asked about their emotions or thoughts while being assessed. The transcript for this section of the interview is shown in Table 7.3. Including a reference to both the emotions and the thoughts might be problematic, but the question was worded this way to prompt students who would be more confident responding initially with an affective rather than a cognitive answer.

Table 7.3: Student thoughts and emotions during assessment

Interviewer	The first thing I’m interested in is the emotions or the thoughts that were going through your head as you were working through the task yesterday. Anyone like to start with what they were thinking about?
Bree	I will.
Interviewer	Yes?
Bree	I was thinking, would I get it done in that time? Will I find all the pieces I need? Will I get to [pause] will I finish it? Will I program it right?
Interviewer	Those ideas were going through your head?
Bree	Yeah.
Interviewer	Do you think you had enough knowledge to do what you had to do?
Bree	Yes and no.
Interviewer	Why yes?
Bree	Because I did it once before and, no, because I had help the first time.
Interviewer	Why no?
Bree	Because I didn’t have a partner to do it with.
Interviewer	Did anyone else find it different yesterday?
Jayne	Because you felt like you were alone and you needed to get it done and you didn’t know how to.
Interviewer	Ellen?
Ellen	You felt like it was hard because your partner would help build it and everything and you get it done twice as fast than you could by yourself.
Interviewer	Do you really think that you get things done twice as quickly when you’re working with a partner?
Bree	Sometimes.
Jayne	Yes.
Bree	Sometimes they talk.
Ellen	Sometimes your partner can give you ideas.

Bree	And they talk.
Interviewer	[Interviewer sees that Sam has not responded and has knowledge of his preference to work alone] Sam, the idea of partners is a bit different for you?
Sam	Yes.
Interviewer	What's your opinion on working that way?
Sam	It's all right because if you need help you don't have to walk all the way out of the classroom to get it. But I would rather work on my own.
Interviewer	So did you feel comfortable in the situation yesterday doing what was required of you?
Sam	Yes.
Interviewer	Any emotions that you felt during the task?
Sam	[Sam shakes head] No.
Interviewer	Any positive emotions that you felt?
Sam	It was fun
Interviewer	What was fun about it?
Sam	Just building the robots.
Interviewer	Ellen, your thoughts yesterday?
Ellen	It was different because I didn't have a partner there and you had someone [assessor] watching you. It felt kind of weird with someone watching you.

Significantly, the idea of working alone to complete the assessment task was an issue for three of the four students. At times in their robotics experiences, Bree, Ellen, and Jayne found it beneficial to work in pairs so that they could "get it done faster" and have assistance when needed. Sam preferred to work alone and he had made this observation during the one-on-one interview conducted with him during the previous month's teach-back episode. Sam's preferred way of working may not have been known to the other students and, at that this point of the focus group interview, Sam had not contributed to the discussion on working in a partnership situation.

Knowledge of the participants' preferences and habits of working were of value in this interview in two ways. First, the interviewer used her knowledge of Sam's mental models of social construction, gained from previous data collection episodes, to prompt him with the question, "Sam, the idea of partners is a bit different for you?" The question had been framed in a way to prompt Sam to discuss his preferred way of working while acknowledging the reality of his differing opinion. Sam was able to provide a frank response, without pressure, due to such demonstration of respect for his individuality.

Second, the interviewer was able to coordinate a fruitful interlude when she asked for Ellen's answer to the question about completing the assessment task. Ellen had allowed other students to respond to questions before she offered her thoughts. This hesitancy to respond was not interpreted as a reflection of her lack of self-confidence. On the contrary, the interviewer knew her to be a particularly confident and competent student who had well-developed opinions on a wide range of issues in learning and assessment. Her hesitancy was due to courtesy. Her subsequent, illuminating response described the "difference" of this assessment activity because someone was "watching" you rather than working with you.

Her reflection highlights the importance of investigations into students' mental models of assessment because it is often the unseen, unconsidered factors that may influence how successfully a competent student completes a task that determines the perception, or otherwise, of capability or success. *Someone is watching you* may have a huge significance for many students who are trying to demonstrate their competence in a domain. This observation was one of many of the small pieces of the assessment jigsaw that were found through this data collection method.

Mental Models of Assessment Design

The focus group discussion uncovered two distinct mental models of the two systems experienced during the assessment activity: the robotics system and the assessment system. The first of these systems, robotics, was the context in which the second system, assessment, was situated. The mental models for both of these systems were often being run in parallel (van der Henst, 1999) by the students as they reflected on the prompts and probes in the interview. This simultaneous and parallel processing of mental models (Newton, 1996) for two separate, yet interrelated, systems indicates that any designed assessment task must be contextualised in order for it to be effectively understood. The design of the assessment task content and process must reflect the nature of the domain. The students' understanding of how the assessment system works within this domain was not a uni-dimensional structure but reflected an understanding of what the system contained, how it worked, and why it worked the way that it did (Carroll & Olsen, 1988): the conceptual, declarative, and procedural knowledge of robotics.

The students had run their mental models of assessment the day before from two points of view — the assessor and the assessed. Now they were being asked to distribute those mental models with other members of the focus group. While they may have been coordinating their responses by answering in turn, they were not merely repeating statements made by others. The focus group interview context allowed a shared mental model of assessment to be being run collectively through the "propagation of representational states" (Banks & Millward, 2000, p. 4), in this case, a verbal reporting of their experiences and understandings.

Types of assessment..

Responses to the question, "What can you do to show the teacher what you've learned?" are shown in Table 7.4.

Table 7.4: Types of assessment.

Bree	Being able to **write** about it.	
Sam	Yep, that was what I was going to say!	
Interviewer	Where would you write about it?	
Sam	In your **journal**.	} *simultaneous*
Ellen	Your journal.	} *simultaneous*
Sam	If you were asked a question about it, and you didn't know what it was, then you probably haven't done it!	
Interviewer	So even though robotics is physical, to show success as a learner would mean that you would be able to write about it?	
Sam	Yes.	

Bree Or **tell** someone about it.

Sam Or **show**.

Ellen Like, **show** them you're **happy**.

Bree **Show** them a **picture**.

Sam **Show what** you've **done**.

Jayne **Show**ing **how** you've **done** it.

Bree **Show** how you **feel**.

Sam It would **show all** of it!

Note: Significant comments or parts of comments have been formatted in bold script to signify commonalities in the responses and demonstrate formation of distributed mental model

The students were bouncing their ideas off each other and becoming quite animated as a shared mental model of assessment was being developed through this series of responses. Their responses confirm a move from general terms or actions such as "write", "tell", and "show" to more specific actions that extrapolate on the action such as showing "what you've done", "how you've done it", "how you feel", and showing "all". Bree and Ellen, and supported by Sam, felt that the inclusion of emotions, such as "how you feel" and "happy", were indicators of success in learning. They were becoming collaborative meaning-makers because they were responding as a group which has experienced common practices of assessment (Jonassen & Land, 2000).

How assessment results can be reported.

Mental models of assessment also contain information about how assessment results may be shown. One part of the focus group discussion raised this issue of reporting results and one student, Ellen, suggested the inclusion of graphs to show a continuum of students' skills and knowledge. All of the participants, at some stage, referred to the need to include a "confidence" scale in a reporting instrument. This unity of opinion about confidence may indicate that there is an important connection between the individual mental models available to work through a problem situation, and the personal belief or self-efficacy (Schunk, 2001; Schunk & Pajares, 2004) that those mental models are sufficient to overcome the challenges within the problem.

The transcript that follows in Table 7.5 shows the development of the students' shared mental models of reporting and how graphs may be useful to illustrate confidence and competence.

Table 7.5: Reporting on assessment.

Interviewer	How would you report on robotics?
Sam	If they're a long way [away] email it or something.
Interviewer	All right. How would it look?
Ellen	A graph.
Jayne	You could have a graph. You write what things they could do well or if they couldn't.
Bree	Writing.
Interviewer	What things would be in the graph?
Bree	Achievement.
Jayne	How they made the robot and if they didn't know how to do one of them.
Ellen	Confidence.
Jayne	The parts and what to do.
Ellen	Like, for the graphing, you could have zero at the bottom and a hundred at the top, and that could be like a percentage. And you could have confidence, how confident they were out of a hundred and then experience and how far they built it, and how much time they used, and how well they used the time.
Interviewer	Who would determine all of those things that went in the graph?
Ellen	The assessor.
Sam	The person who did it. Get their opinion on what they think happened.
Interviewer	So the students themselves? Give their opinion?
Sam	Yes.
Interviewer	Why is that important?
Bree	Well [pause].
Sam	Because, if there's something they think that they did better, then they could tell the assessor and the assessor could go and see, or think about it, and try to remember if they did better or not.

This part of the discussion raised the issue of who should contribute to the development of authentic assessment tasks (Barlex, 2007; Jonassen, 1995; Royer et al., 1993; Stripling, 1995). After Ellen proposed the assessor as the determiner of what went in the graph for reporting, Sam suggested that assessors might also incorporate students' opinions in the development of strategies. This inclusion indicates that his mental model of assessment contains experiences where he may have felt he could have contributed to the assessor's appreciation of his learning journey. Assessment practice might, otherwise, be perceived as inequitable.

The perception of inequity, that often occurs when communication is deficient, could be influenced by the student's mental model of learning and assessment that has been created through past experience. Stein (2004) stressed the importance of teacher feedback in the form of meaningful dialogue between students and assessors at all stages of assessment. Clear, communicative reporting practices that incorporate dialogue with the students, could avoid such perceived assessment inequities.

One of the strategies, used by the researcher in this section of the transcript, highlighted how the use of unambiguous questioning, using terminology at the level of the students, can contribute to the collection of valuable information from interview participants. The interviewer asked, "How would it [the assessment] look?" and Ellen responded with the suggestion of a "graph", for which she later gave a vivid, clearly-structured description (Table 7.5). This rich response demonstrates that opportunities for participants to describe how something looks are recommended as a necessary research strategy when working with middle years students. Ellen demonstrated how two functions of mental models, diagnostic and communicative, can merge to create a valuable artefact, the graph, that would contribute to a possible assessment approach.

How assessment can show what you have learned.

The next part of the transcript (Table 7.6) shows how the students responded to the prompt, "What can you do to show the teacher what you've learned?" Bree once again started this discussion of what can be done to demonstrate learning.

Table 7.6: Showing what you have learned (A).

Bree	Show the teacher you can **write it down**.
Interviewer	What would you show the teacher?
Bree	Ask her to get you to **build a robot** and try to be able to do it.
Jayne	You could **build a robot**, pick a program on the computer, and download it so she can see what you've learned.
Interviewer	Do you think she'd do the same for everyone?
Bree	[Negative head shake]
Ellen	No, because we might have **different abilities**. Some might have more turns [goes] than other people.
Interviewer	So that's okay?
Bree	Yes, because people have **different strengths**.
Ellen	Like **some people like it** (robotics) **better** than us three (Bree, Ellen, Jayne) would.
Interviewer	So that's the way you would like to be assessed?
Bree	Yes.
Sam	[Nods his head]
Jayne	[Nods her head]

Note: Significant comments or parts of comments have been formatted in bold script to signify commonalities in the responses and demonstrate formation of distributed mental model

This excerpt provides substantial evidence that these Year Six students have developed mental models of assessment that include the requirement for different tasks of assessment to suit different students due to their ability, strengths, and interest (bolded font, Table 7.6). This matching mental model of equity in assessment, through the provision of different assessment tasks or strategies for students was demonstrated by all students. Sam did not verbally enter the discussion on this topic until later (Table 7.7). Bree, Ellen, and Jayne's mental models of assessment had also indicated a match due to the compatible demonstrations of competence through "doing" and "showing" (Tables 7.6 and 7.7). One of the difficulties with designing assessment in the robotics domain is the ease with which competence is only attributed to the completion of a final product — a functional robot.

Reeves (2000) believed that important conceptual knowledge may not be directly observable but only inferred by observing students' performance on a range of cognitive tasks. The complexity and individuality of mental models of learning and, particularly in the problem-solving domain of competence, may require multiple settings so that the mental models' capacity to contribute to a student's robust learning journey can be determined. The students, in this study, were building a powerful picture of the multi-faceted assessment strategies that were possible within a constructivist/social constructivist domain.

The shared mental model of individual capabilities, and the way that these can be shown, were further developed as the discussion continued. Table 7.7 shows how the transcript in Table 7.6 continued after Sam was asked how he might demonstrate his competence in robotics.

Table 7.7: Showing what you have learned (B).

Sam	I might keep **photos**. Show them to the assessor.
Interviewer	From one day or over a period of time?
Sam	Could be both.
Ellen	Yeah, if you **use pictures to record** the first idea you have from the start and keep them at the end, and the teacher can see how much you've learned from them.
Sam	Recently I made a **portfolio** because I had to go for an interview at my new school and I had to show the principal what I've done.
Interviewer	Would that be a good assessment for robotics?
Ellen	Yes.
Sam	Yes, **type it up and put them in**.
Jayne	Take a **photo of the robot** that you built.

Note: Significant comments or parts of comments have been formatted in bold script to signify commonalities in the responses and demonstrate formation of distributed mental model

Sam's experience of creating a digital portfolio, where evidence of his ability was required, informed his mental model as to how this format was sufficient to demonstrate his competencies in a variety of areas. Portfolios are seen (Herron & Wright, 2006; McNeil, 2007; Saddington, 2004; Wiggins, 1989) as part of authentic assessment strategies that have educational value in their own right. This value might be associated with the methodology of sample collection and the match of such artefacts to perceived capability. Wilks (2005) believed that portfolios shed light on the rationale behind the choices that students make on what is included and how it is presented. Herron and Wright (2006) proposed that a portfolio is an indication of the learning journey because it grows over time as more evidence is added. Nevertheless, caution on their use is recommended (Givens, 1998; Kimbell, Stables, Wheeler, Wozniak, & Kelly, 1991) particularly if a narrow interpretation of the structure of contents is applied as it stifles the very individualistic approach that was envisaged in the first instance. Caution is also recommended if their production becomes overly prescriptive (Kimbell et al., 1991, 2002) and there is no opportunity for the student to have some discretion or choice as to what is included that could provide evidence of the individual learning journey.

During the focus group interview Ellen described how a series of photographs could create a sequence of ideas to show how they have developed. Sam understood that the portfolio would “show the principal what he had done” as evidence of his development of ideas. Ellen and Sam shared a mental model of assessment that excluded the actual artefact, “the robot”, and replaced it with the artefact, “the portfolio”, that would best indicate to the teacher what they had learned. The portfolio became evidence of their learning journey and was, therefore, a valid assessment strategy in this domain. The discussion on the design of assessment provided rich responses from the students ranging from opportunities to show “all” of what we know (Table 7.4) to the use of graphs for a confidence scale (Table 7.5) and ending with the creation of a portfolio as evidence of an individual’s learning journey (Table 7.7). The students offered small pieces of the puzzle that were continuing to be placed in a comprehensive jigsaw of a shared assessment mental model.

Mental Models of Assessment Help

This section discusses the level of assistance that could be given without affecting the rigour of the assessment task. This issue was seen as relevant when raised by the students during the preparation for the assessment episode. The topic was visited in the interview where Bree continued to be the catalyst for each new discussion, although her comments were brief. She was, in this role, enhancing the coordinated performance of the team although, here, we were not operating in a tank simulator (see Minionis, 1995 in Banks & Millward, 2000) but in a discussion focus group!

How much help is too much?

The students had provided help, in some form, to each other while completing their tasks in the assessment episode held the day prior to the focus group interview. The question, "How much help is too much?" (Table 7.8).

Table 7.8: How much help is too much?

Bree	A **little**.
Jayne	A **little bit of advice**.
Bree	If they were struggling you could **help them**, **but not** actually **tell** them what it was.
Ellen	Don't give them the answer. Give them **clues** on how to get the answer.
Jayne	Yeah.
Sam	Say, "You've done **something wrong there",** and let them check it out.
Interviewer	So, how much help is too much?
Bree	Actually giving them the answer.
Jayne	Or building it for them.
Bree	Yeah.
Jayne	Doing the computer program for them as well.
Bree	Giving it to them.

Note: Significant comments or parts of comments have been formatted in bold script to signify commonalities in the responses and demonstrate formation of distributed mental model

Consensus seemed to be reached about the appropriate level of assistance that could be given to students who were doing an assessment task and this involved giving "clues" or suggestions that something was wrong in a certain place and encouraging them to “check it out” for themselves. Ellen also offered other suggestions such as, “give them more time” or “assess them on something easier” if the student was struggling too much during an assessment activity. The students’ comments continued to build an emerging picture of the validity of individuality within assessment strategies through the recognition that the one-size-fits-all approach is not an appropriate method to assess learning.

Reeves (2000) included factors such as social learning and collaboration in his subset of skills in cognitive assessment. These factors incorporated peer assessment and self-evaluation (Benson, 2003) that would contribute to the level of metacognition being developed by individual learners. Social learning (Reeves, 2000; Smagorinsky, 1995; Vygotsky, 1978) also involves the recognition that others are beside us on our learning journey and the ability to recognise areas where they may need assistance, as well, helps to inform an individual of their own learning requirements for completion of a task. Giving advice or help involves using mental models of learning and problem-solving as well as ones of social negotiation. The students’ mental models of social construction, while at variance due to their preferred way of learning, were robust enough to recognise that others had both different skill levels and confidence to negotiate successful problem-solving situations.

Is completing the whole task necessary?

There was no consensus, however, on what constituted a sense of achievement when completing a task. The students had different mental models on what level of completion of a task equated to a sense of achievement (Table 7.9).

Table 7.9: Is completion of the task essential for achievement?

Interviewer	How would you feel when you didn’t finish the task?
Bree	Uh, it didn’t feel that bad because I knew I had tried it.
Interviewer	[Five second pause] [Interviewer asks another question] If you were successful, how did you feel?
Sam	Good.
Interviewer	Why?
Sam	Because you finished it. Gave me a feeling of achievement.
Interviewer	Okay, so you only have a feeling of achievement when you’ve actually completed something?
Sam	Unless [pause]

Ellen	No. You might have a feeling of achievement if you had trouble with that last time and you passed the bit you had trouble with.
Sam	Or at least done a big part of it.
Interviewer	So, is the completion of the whole project essential for you to feel like you have learned?
Bree	No.
Sam	To the max, yes.
Interviewer	To the max?
Sam	Yes.
Interviewer	So maximum learning is completing it?
Sam	Yes.
Bree	No, not really. Because, if you have trouble with it, you could learn a lot more if you ask the teacher or somebody else who has completed it.

The students' mental models of what was "maximum learning" differed and were prompted by the simple question, "Maximum learning is completing it?" Sam, who was a confident investigator in the robotics domain, usually had little difficulty in finding his way through problems. He had designed a seemingly impossible assessment task for Jayne that involved attaching four motors to the robot. His mental model of learning was informed by his confidence with this area of investigation as well as his creativity that inspired him to believe that a four-motor robot might be possible. Sam was working outside of the safe, inflexible rubric-style assessment strategy (Kimbell, 2002) often employed where teachers give marks to students who demonstrate "evidence" of attainment.

The other students, apart from Jayne who did not contribute to this part of the discussion, held different mental models of learning to Sam. Bree, who was a methodical problem solver, valued the opportunity to learn about challenging areas by asking the teacher or others who have displayed competency. She did not believe that you had to complete the entire project or task in order to learn. Ellen's mental model of learning appeared to match Bree's mental model because she described achievement in learning as being able to “pass the bit you had trouble with” that indicates a focus on skill development and understanding (Pintrich & Schunk, 2002).

These mental models of learning and assessment would indicate that there was some accord or match as to the type of assessment that showed what learning had taken place. Nevertheless, it was becoming evident that while there were areas of strong accord, there were also areas of opposing views. The focus group interview had provided a rich source of data from which to make analysis.

Matches and Mismatches of Mental Models of Assessment

The students were required to complete end-of-year journal entries at this time as part of the summary for the robotics activities for the year. All 52 students (58 had commenced the learning experience, Chapter 3) completed a journal entry in November 2005 as part of Pamela’s assessment strategy. This entry provided valuable information for the study of mental models of assessment. The entry was completed one week prior to the focus group interview and asked, “What assessment would be suitable for showing what you have learnt?” Table 7.10 shows the entries made by the four students who participated in the focus group interview.

Table 7.10: Student journal entries about assessment.

Student	“What assessment would be suitable for showing what you have learnt?”
Bree	I think that a written assessment would be suitable for showing what I’ve learned.
Ellen	A chart or PowerPoint presentation, because you write and do pictures of what you learned.
Jayne	Doing all the stuff in front of you, like doing a program with the IR and robot.
Sam	I would let you give me some pilots to do and I’d complete them. And a tap dance as requested!

This journal entry provides a valuable source of comparative data with the ideas from the focus group interview. The data in a journal entry is less likely to be influenced by nuances from an interviewer (Burns, 2000), or from the possibility of “group think” (Babbie, 2007, p.309) where conformity to a shared view is possible. Two of the four student participants referred to undertaking a writing task while two suggest the completion of a construction and programming task to be a relevant assessment strategy. These were not reflective of the responses from the entire study population (N=24) whose multiple responses to questions about preferred assessment type and how best they can show what they have learned included:

- demonstration of robot making N=26;
- PowerPoint ™ presentation N=14;
- written test or description N=9; and
- oral description N=4.

Bree's journal did not explain what her "written assessment" involved. However, Ellen provided more detailed criteria for her writing task where pictures and text about what had been learned would meet the basic requirements of a portfolio. Jayne and Sam had matching responses because both referred to the completion of a program/construction task. Sam's "tap dance" was either a humorous response or an editorial comment about the negative "trained-dog" style of performance often seen in assessment items.

Data from the post-experience interviews, journals, the teach-back episode, and the focus group interview produced comprehensive information of the participants' mental models. Table 7.11 combines this data on their mental models of assessment with descriptions of preferred assessment strategies and the general purpose of assessment.

Table 7.11: Participants' mental models of assessment from four data sources.

Participant	Assessment	Mental Model
Pamela	Strategies	**One-to-one conferencing #** Show what they have done Video tape what they're doing Writing in their journal **Peer assessment on group functioning #**
	Purpose	Use of problem-solving strategies **Being self-reflective #** Making progress and having some success
Bree	Strategies	**A written assessment #** Write it in our journals Build a robot and try to be able to do it
	Purpose	Levels of confidence The technique used Achievement

Ellen	Strategies	Show/tell Teaching someone else **A chart or a PowerPoint presentation because you write and do pictures of what you learned #** Build the robot Go on the computer and build a pilot
	Purpose	Levels of confidence How well they did it, technique used **[process of building robot]* How well they built it **[product of building robot]* If they had trouble programming and building
Jayne	Strategies	Build a robot, pick a program and download it Showing how you've done it Take a photo of the robot you built
	Purpose	Levels of confidence Remembered it **[declarative and procedural knowledge]* The student could go into it straight away **[process of building robot]* The student would know how to do it **[process of building robot]*
Sam	Strategies	**Testing - doing robotics tests #** Keep photos Write about it in your journal Teaching others **Entering robot comps #** **[competitions]*
	Purpose	Creativity, that's themselves **[individually created program]* Not in the book and hasn't been tried **[new program*] Use of problem-solving strategies Skill and **being independent #**

Notes:
 # mismatch – individual response not repeated by any other participant
** [interpretation of response for reader comprehension]*

Pamela stated in the post-experience interview that she believed all students would prefer to "show what they have done as opposed to writing". Her assumptions of students' mental models of assessment incorporated their preference for oral presentations rather than written work or pen and paper tests. Her mental model had been informed by her close association with the cohort of over 50 students and her constant observation of their interactions in the robotics laboratory. This mental model is supported by research (Chervin & Kyle, 1993), where written test results were compared to oral contributions in class and outcomes indicated that the reasoning skills addressed in the written tests allowed information to be gathered on only a small portion of the students' ability.

Pamela's mental model of assessment contained the following three fundamental strategies:

- Conversing — discussions with students about what they know,
- Showing — physical construction and programming of the robot, and
- Recording — ongoing record that students control through journal or video.

Each seems to correlate, respectively, with Wilks' (2005) idea of authentic assessment's naturalistic performance and portfolio style.

The data in Table 7.11 demonstrates that the four students' mental models of assessment matched those of their teacher in many areas but also contained some mismatches with each other, and with Pamela. Ellen included a specific "conversing" strategy in her discussions of "show or tell" that was distinguished from "teaching someone else" (Ellen, Post-experience Interview, 5 September 2005). Sam also included a "teaching others" strategy, creating a matching mental model to Ellen.

All four students excluded a specific oral assessment strategy although Pamela believed that they would be more at ease with oral conferencing than any other assessment task. This was a clear mismatch between their mental models on assessment. The mismatch is even more pronounced given that this was Pamela's primary form of assessment for reporting. The students had either not incorporated this information about conferencing into their mental models of assessment or Pamela had not clearly communicated to them that this method of assessment would be used for their end of year report. This was the most apparent mismatch, although there were some surprising inclusions in the assessment strategies suggested by the students.

While the four students contained a "showing" element in their assessment strategies where a student would be required to build and program a robot to demonstrate what they had learned, Bree, Ellen, and Sam also included a writing task. Pamela included writing as a journal-linked strategy only, because she believed that they would prefer to "be able to show what they have done as opposed to write it or do a presentation of any sort" (Pamela, Focus Group Interview, 26 November 2005). She also believed that the structure of their preferred assessment strategy would be "one-to-one, to be able to go through it and actually show step-by-step what they've learnt" (Table 7.11). Pamela confirmed the use of journals at this time as well, and she believed that the students would “expand their journals” of their own accord to encompass assessment strategies. Two students, Bree and Sam, mentioned the term, “journal”, as assessable in their assessment items, but all of the students did refer to journals when discussing recording what they had learned during the focus group interview.

The idea of using the journal as a valid assessment strategy, seemed to have been communicated clearly although Pamela acknowledged that “journaling’s fairly new to them and I think, with time and some scaffolding and some support, that will become stronger” (Pamela, Focus Group Interview, 26 November 2005). She confirmed the value of a portfolio of work, referred to as well by Ellen, Jayne, and Sam when they proposed keeping photographs of completed robots during the focus group interview. The journals, therefore, were a part match and, showing or demonstration through physical construction or photographs of such encounters, were a clear match.

Sam included the idea of entering competitions as part of his assessment strategies (Table 7.11) indicating that he was clearly comfortable with competition within this domain. His mental model of assessment also included the idea of creativity and this might support his inclusion of competition as a way of assessing competence. Sam described creativity as something “not in the book and hasn’t been tried” and the unpredictability of a competition would also provide tasks that were outside the experiences of the “book”. This perception might also explain why Sam’s mental model of assessment included “doing robotics tests” as a strategy. While Sam did not extrapolate his use of “test” terminology, it is clear that he linked the assessment tasks designed and implemented by the participants prior to the focus group interview as a valid way of assessing capability and confidence in robotics construction and programming. This clear mismatch to other participants reflected Sam’s mental models of learning with robotics that were independent and creative.

A clear mismatch was Pamela’s inclusion of peer assessment in her mental model of assessment strategies (Table 7.11). The four students did not include assessing their peers at any time during the focus group, the teach-back, or the post-experience semi-structured interviews, even though they were specifically asked who else might have an opinion about their capabilities during the focus group interview. At that time, Bree was the only student to offer that “the person who you worked with” might have an idea of your competencies. No other journal entry offered the option of peer assessment. The entries in the students' journals at this time (Chapter 3) required them to describe or, at least, give some direction as to who were the best workers in their group. This low-level peer assessment was not referred to by the students during the focus group interview, without prompting, indicating that it did not form part of their mental models of assessment. Peer assessment, therefore, was a clear mismatch with Pamela's mental model of assessment because "peer assessment on group function" was one of her preferred assessment strategies (Table 7.11).

One other mismatch was the requirement to be self reflective (Table 7.11). Pamela had a focus on engaging the students' metacognitive strategies that would require the ability to be self-reflective. The act of being a reflective learner has much to do with conceptual tempo (Kagan, 1965, 1966; Kagan & Kogan, 1970; Cassidy, 2004). This refers to the degree to which learners are cognitively reflective and more likely to examine alternative hypothesis when validating responses. At no point did the students include a specific requirement for self-reflection in their assessment strategies, although the fact of writing a comment in their journal at the end of each robotic activity required them to reflect on their achievements.

While it is easy to concentrate on the notable mismatches, the matches themselves tell a very powerful story of how mental models are created and moderated in a rich, interactive learning environment. What is of concern to many professional teachers is that "real" or authentic assessment of the actual learning journey may take considerable time to communicate or demonstrate. If, as our research participants proposed, assessment of learning in a technology domain, such as robotics, could be suitably designed around demonstration through action and/or through portfolio creation, and through oral discussions, then the largest item to be invested in this process is time.

Negotiated strategies facilitate the demonstration of meaningful, student learning (Kimbell, 2002; McLaren, 2007). Pamela made some explicit observations about what students can offer to the assessment process including:

> We make presumptions about what these kids know about assessment and how it should all go together and who makes the decisions. You can really see, from the four kids, that they're quite aware what needs to go in and what doesn't need to go in. As a learner, they can make the decisions about what needs to be assessed (Pamela, Focus Group Interview, 26 November 2005).

If teachers value the determination of what students know before teaching new concepts, then a similar investment should be placed in determining how that learning will be assessed. Having clear mental models of what assessment strategies are to be used helps ensure students can fully contribute their understanding of their journey. If they do not have a clear mental model of the purpose, design, and function of the assessment strategies, then a full sequential picture of their learning journey cannot be produced. If we have multiple ways of knowing, then there should be multiple ways of demonstrating that knowing. Active engagement in learning can then be reciprocated with active engagement in assessment.

Where To Now?

This chapter finishes with more pieces of the jigsaw concerning the mental models of assessment of learning journeys. Papert (1980) found that it was important to concentrate on "individualised heuristic strategies" (p. 183) of teaching in classrooms instead of a homogenous approach that would try to capture all individuals. In a similar vein, teachers must question how they can claim to be instantiating individual approaches to learning if they then apply a standardised assessment instrument to measure the results of that heuristic approach. No continuum, regardless of its complexity, could possibly capture all the different pathways of learning that a class of students follow. Assessment is *part of,* not an adjunct to, an individual's learning journey; therefore, clearly defined signposts can establish the attainment of goals along the way.

Nevertheless, the jigsaw is not quite complete and the final section of the journey is yet to be transversed. Bilbo was continually adding pieces to his adventure jigsaw and, as he concluded his final interactions with Smaug, the dragon, Gandalf told him, "You aren't nearly through this adventure yet!" (Tolkien, 1937, p. 212). We may seem to draw near to a conclusion, but there remain further matters to investigate, other questions to pose, and more mental models to determine.

CHAPTER EIGHT: *Longitudinal Mental Models (March 2006)*

> There is nothing like looking, if you want to find something. You certainly usually find something, if you look, but it is not always quite the something you were after (Tolkien, 1937, p. 55).

Introduction

This chapter is a return journey. When we undertake a journey we are looking for something, but we may unearth something richer, more valuable, and of greater significance than that which we anticipated. One of the first propositions made in this study was that mental models enable many problem-solving strategies to be implemented by learners in order to negotiate a path through the often difficult challenges of their learning journey. An understanding of those mental models is essential for productive pedagogical practice and authentic assessment strategies.

While mental models that match can promote learning, due to the homogeneity of perception, application, and communication strategies between the teacher and students, those that mismatch are of obvious concern due to their potential to reduce the effectiveness of the teaching, learning, and assessment environment (Bibby, 1992; Henderson & Tallman, 2006; Johnson-Laird et al., 1986; Larkin & Simon, 1987). This study uncovered obvious mental model mismatches between the teacher, Pamela, and some of her students as well as among the students themselves (Chapters 5, 6, and 7). Because of the study's relevance, the ramifications of these mismatches were further explored to determine the significance of their impact on effective teaching, learning, and assessment.

A Longitudinal Study

This chapter investigates the mental models of the five participants four months after the last data collection episode on 26 November 2005 (Chapter 7). By March 2006[7], two of the students, Jayne and Sam, had moved to other schools closer to their homes. Bree and Ellen remained on site as did their teacher, Pamela, who was teaching a new group of Year Six students. Bree and Ellen were in separate Year Seven classes in 2006 but were studying a similar curriculum that had been designed cooperatively by their teachers. The interviews were semi-structured of 30 minute duration. Bree and Ellen were interviewed separately at the school site, in an empty

[7] The final longitudinal data were collected in October 2006 (Chapter 9: A longitudinal case study).

classroom with another teacher, not associated with the project, in the room but not within hearing distance of the interview. Jayne and Sam were interviewed in their respective domestic residences, where one of their guardians was present in the room, but not within earshot of the interview. Pamela's one hour interview on was conducted in her domestic residence to accommodate family and work considerations[8].

Questions for these longitudinal, semi-structured student interviews (Appendix O) followed similar themes as those interviews conducted in March and September 2005. The themed questions were pre-prepared and aimed to address topics such as:

- o working in groups of two or more,
- o problem-solving,
- o metacognition, and
- o assessment.

Interview questions (Appendix P) were also pre-arranged for Pamela and followed similar themes to those used in the students' interviews to establish her mental models and her assumptions about those held by the students.

A longitudinal study, such as the one undertaken in this project, aims to recognise changes that occur over time (Cohen et al., 1995). Unfortunately, the class and school changes altered the relationships among the participants. Pamela, alone, continued working with robotics in a formal context. Hence, the interviews focussed on the participants' reflections of past events with robotics and how they might link those experiences with their current teaching, learning, and assessment experiences, in light of the topics above. Also, the responses provided by the students may have been influenced by the intervening months spent in different classes and schools with various teachers who would, themselves, have individual teaching, learning, and assessment strategies. Ascertaining the influence of such strategies is beyond the scope of this study.

Mental Models of Teaching and Learning

Working in Groups of Two or More

The students had experienced varied levels of engagement and success when working in groups of two or more during the robotics learning experience in 2005.

[8] Interviews with participants were conducted on 16, 17, &18 March, 2006, respectively.

Pamela had endeavoured to create groups where students who shared similar interests would be working together (Chapter 4). However, the skills and attitudes students require to collaborate efficiently and effectively for eight months may be difficult to develop and sustain. The unavailability of the required mental models for sustainable interaction raises particular issues when students are investigating problems in a domain that is both novel and challenging.

In these March 2006 interviews, the students were asked to respond to various questions regarding the issues of working in a social-constructivist environment. Generally, their responses remained consistent with those that were provided in the post-experience investigations in September 2005. This consistency of response validates the mental models determined at that earlier point in time and supports the proposal that robust mental models can be stored in long-term memory for retrieval at a future time (Gentner & Stevens, 1983; Henderson & Tallman, 2006).

The first question, regarding social construction, involved the students retrieving mental models of whether a socially-constructed way of working helped them learn more than they would if they worked by themself. This part of the inquiry replicated Likert Scale Questionnaire items and interview questions from the post-experience data collection episode in September 2005 (Appendices G & K). The results indicate that the students had not altered their mental models of the benefit of working in groups: Bree did not agree that she would learn more in a group while the other three students, Ellen, Jayne, and Sam, continued to maintain that you can learn more when working in a group. However, the arguments that the students cited as justification for their mental model, did vary from those given in the previous year (Table 8.1).

Table 8.1: Student responses about working in groups.

Student	Responses
Bree	It [working in groups] doesn’t really help me because the group I was in, when I did robotics [in 2005], wouldn’t let me do it because I was the girl and they expected me to not know how to do it.
Ellen	It [working in groups] helps you learn. You could both work on two different things and you could get it done quicker. You can have different ideas from your group mates.
Jayne	It [working in groups] helps you work with other people. You only learn something if someone knows something that you don’t.
Sam	You get different ideas that you could try and you’re getting a different perspective.

Bree's mental model included her role as an "outsider" in her group. While she preferred to work on her own, because "I like to do things my way and within a group you've got to vote to choose a way" (Bree, Longitudinal Interview, 17 March 2006), her reason for not learning more were other students not expecting her to have sufficient knowledge to contribute due to her gender. Although the gender variable was beyond the research parameters, this insight indicates the relevance of subsequent gender-related studies.

Bree included a further justification for working alone: if someone else is "doing it" then she "wouldn't learn that much if the other person was doing it for you". Nevertheless, she believed that, if you were with people with whom you "got on", then any exchange would help all members learn more. This retrieved and linked mental model of working in groups had not altered from Bree's post-experience mental model (Chapter 6) and demonstrated that, either the preceding robotics experience had reinforced an already strongly-held mental model and/or that, since that experience, nothing had occurred that would challenge the mental model's efficacy for her as a learner.

Bree's mental model of working in groups could control her actions during other group engagements. Some positive experiences, besides those with whom she "gets on", may be necessary for Bree to modify, or even abandon, this ineffective mental model (Seel & Strittmatter, 1989) so as to avoid any stultifying influence (Henderson & Tallman, 2006) that it might have on her ability to engage with other learners. If a teacher is unaware of such a situation, where a strongly-held mental model may continue to influence a student's perception of their learning capabilities well into the future, then the student may have no opportunity to effect a change.

Yet, how does a teacher become aware of such strongly held mental models without investigating each student's mental models on a regular basis? Is it as valid to investigate students' mental models on, for example, the efficacy of working in groups as it is to test their ability to complete long division in mathematics? If mental models "form the basis of all human behaviour" (Barker, van Schaik, & Hudson, 1998, p. 104) or, as Norman (1983) believed, "are what people really have in their heads and what guides their use of things" (p. 12), then understanding students' mental models of working in groups is a fundamental requirement before any effective long term social construction of knowledge can be expected. Investigation into the mental models with which students approach an area of learning should be more than a simplified needs assessment (Stripling, 1995) that, at best, focuses on discovering just their declarative knowledge.

The opportunity to be reflective appeared to be of significance to the students as they offered insightful reasons why working in groups is beneficial for learning. The other three students also retrieved mental models that you can learn more by working in a group (Table 8.1). These were consistent with those expressed in the post-experience, data collection episodes in 2005 (Chapters 5, 6, & 7). Ellen acknowledged that no one actually taught them how to work in groups but that working effectively means putting your "opinions together"; Jayne believed it helps you "get better"; and Sam suggested that "you get everyone's idea and then you sit down and think about it for a minute" before deciding which idea you are going to use. Their mental models of working in groups held a predominant view of a positive social environment where opinions or ideas were shared, considered, and applied to solutions resulting in learning and matched those held by their teacher, Pamela. She stated that all students are "social creatures" who "learn vicariously" because, in a group, they have the opportunity to "talk things through" and "consolidate things in their minds" (Pamela, Longitudinal Interview, 16 March 2006).

However, further investigation challenged this apparent match. Pamela's retrieved mental model of students working in groups also held the belief that the students are not "consciously aware of the fact that they're social learners and that they learn in a social context". Her comment was surprising in view of her pedagogical practice of ensuring that learners were active and reflective investigators in socially-constructed learning environments. Pamela might be referring to the students' perceptions of what constitutes learning rather than social interaction. So, did the students' mental models of working in groups affect the quality of that interaction: the product they produced? It is important to establish the link, if any, between the perception of success and the outcome of the social learning process because the mental models uncovered, in this area, will help to clarify whether or not Pamela's assumption of the students' mental model of social construction was a match or a mismatch.

During the post-experience, semi-structured interviews in September 2005 (Chapter 6), the students were asked to compare the robot they could construct on their own with the robot they could construct with their group members. This question drew the researcher's interest because it was the item that scored the highest “unsure” responses in the post-experience Likert Scale Questionnaire in September 2005 (Chapter 6). This noteworthy response indicated that there was substantial uncertainty in the mental models held by those eight “unsure” students at that time about the comparative quality of the robots they could construct and program. The four student participants expressed inconsistent responses over time about their mental models of comparative individual versus group robot quality (Table 8.2).

Table 8.2: Student responses about the comparative quality of robots.

Student	The robot I make with my group will be better than the one I would make alone		
	Pre-experience March 2005	Post-experience September 2005	Longitudinal March 2006
Bree	Yes	Unsure	Yes
Ellen	No	Unsure	Unsure
Jayne	Yes	Unsure	Yes
Sam	Unsure	Yes	No

The mental models retrieved (Table 8.2) may each have been influenced by other mental models held at the time, indicating a dynamic isomorphic mapping effect (Johnson-Laird et al., 1998) on the consistency of form that they take. The recursivity of how mental models call upon themselves during processing and self-reflection (Power & Wykes, 1996) may have enabled these students to constantly review their mental models of comparative robot construction.

In the interviews held in March 2006, Bree and Jayne elaborated that groups often contain students who might know more than others. For them, this fusion of capability provides opportunities for ideas to be shared and, synergistically, contribute to a better robot. In contrast, Ellen expressed her uncertainty as to the comparative quality of robot construction in several ways. First, she believed that the quality of the robot could “vary”; a reasonable and possible outcome. Second, she acknowledged you can put more ideas together when there are more people; again a reasonable outcome for group dynamics. She then tempered the expression of these positive outcomes by stating, “you might also have a good idea that you want to keep to yourself”. This desire for an individualised exploration of robot construction and/or a competitive view of achievement could, Ellen believed, enable you to construct a better robot on your own. While Ellen ran her mental model she was incorporating a sense of self into the mental model of social constructivism thereby indicating the evolution of a dynamic mental model that recognised the possible outcomes of, and reasons for, working in either situation. Sam's constantly evolving mental model clearly mismatched those of the Bree, Ellen, and Jayne because he now expressed certainty (Table 8.2). During Sam's interview he stated that he would make a better robot on his own because "you don't have to take ideas from anyone else" and "you can just do what you want".

These mental models, of comparative robot quality and the contribution of others to the quality of construction, indicate constant modification. This evolution could be a reflection of the changing perceptions of success that the students have of themselves as they moved forward on the learning journey.

It is evident that the students' mental models of the comparative quality of robots made in a group are capable of being influenced by a variety of factors, such as: group dynamics, contribution of ideas, competitive individual achievement, a willingness to share such ideas, and the value of individual exploration (Chapters 4 & 6). It is a complex mental model because individuals, themselves, are multifarious as are the relationships they establish. Group dynamics may be ephemeral in that the substance that contributes on a given day to successful outcomes may be hard to grasp, explain, or even be gone the next day when further group work is instantiated. The mental model for comparative quality of robots appears to incorporate a variety of sub-mental models such as robot functionality, quality, success, social efficacy, and self efficacy. It is this complexity that contributed to the variation in responses that the question evoked each time it was revisited.

The mental model of the comparative quality of robots that Pamela held from the beginning of the study, in March 2005, and reconfirmed in September 2005 was that the group robot would be "better" (Item 13 Pre- and Post- Likert Scale Questionnaires, Appendices F & H). During the interview on 16 March 2006, she stated that the outcome of the interaction "depended on the student"; a response that could equate to "unsure" on a Likert Scale Questionnaire. She held that the cohort of 54 students in 2005 demonstrated they "were independent thinkers" and that the "vast majority of them enjoyed working in a group" and this is why she had endeavoured to place divergent thinkers together in an attempt to have them be “attracted to what they need as a learner”. Through such statements she was acknowledging that, while the students continued to operate as individuals, they were also capable of recognising the deficits in their own skills. Pamela believed that the students would actively work with other students in order to overcome these deficits.

The variety of mental models, expressed by all participants, throughout the study period, demonstrates that a homogenous approach may not be necessary for success. The motivation to achieve personal efficacy encourages students to negotiate their socially constructed learning experiences with some effectiveness. Providing opportunities for heterogenous group exploration could provide students and teachers with the best opportunity to develop the mental models required to achieve success.

Problem-Solving

It was anticipated, during the pre-experience data collection period in March 2005, that the mental models of problem-solving the students already held would enable them to operate, at some level, within the domain even if they had an incomplete conception of robotics (Williamson, 1999). This prediction, a function of the researcher’s mental model, proved to be correct as evidenced by most students’ ability, after only one exposure to the equipment, to construct a simple robot and to program it to move forward successfully (Pamela’s Journal, Appendix U).

The constant running of applicable mental models of problem-solving, while they investigated the robotics domain, subsequently enabled students to gain a richer understanding and knowledge of constructing and programming robots. The successful application of declarative, procedural and, especially, conceptual knowledge strengthened the mental models and their inter-connectedness within the students’ personal networks of understanding (Henderson & Tallman, 2006). The successful application of problem-solving strategies can be explained by the improved quality of the mental models the students were constructing, engaging, and adapting (Gott et al., 1988) as they progressed on their robotics learning journey.

Teachers have certain expectations of students and how they will apply the problem-solving strategies that have been taught in particular learning domains. These expectations are usually expressed as learning outcomes and measured by assessment instruments. It might be expected that the approaches that students use to solve problems should progress from a formulaic application of skills (Henderson &

Tallman, 2006; Barker, van Schaik, & Hudson, 1998), such as those shown by Jayne (Chapters 5 & 7), to a more individualistic retrieval of mental models that are appropriate to the creation of a solution, particularly in unpredictable situations (Sloboda, 1996) (Sam's assessment design in Chapter 7).

The students were asked how important successful problem-solving strategies were for effective learning. The context of robotics was not specifically stated and the students were encouraged to contextualise this question individually. Three of the four students, Bree, Ellen, and Sam provided homogenous responses, thereby demonstrating that they had strengthened their personal mental models of problem-solving during and after the robotics experience. These are evidenced by their reference to the individual pursuit of a way to solve a problem (Table 8.3).

Table 8.3: Student responses about the importance of problem solving skills

Student	Responses
Bree	You research about it [the problem task]. You find answers.
Ellen	You learn better. You learn [even] if you don't get it [the problem task] out. If everyone just told you what it [the problem task answer] was, you wouldn't be able to learn. You think about it.
Jayne	It [problem-solving] will help you get it [the problem task] done. If you don't know how to solve it, so you ask someone else to help you.
Sam	You kind of learn them [strategies] yourself. The most important one [strategy] would be going over what you've done. You check up and do it exactly [sic].

Jayne had a mental model of problem-solving that did not match the other students because of its reliance on someone else to provide the answer or solution for a difficult task. While Jayne acknowledged that using problem-solving skills will "help you get it done" (Table 8.3), she only nominated the strategy "asking for help". She admitted that, when faced with a problem, she did not want to stop working, but her mental model of continuing to work was to try to solve it by repetitious behaviour, including re-programming a correct computer program, or ignoring the problem and moving to another task (Chapters 5 & 7).

Jayne clarified her mental model further, during the interview, with an observation that the teacher, Pamela, did not teach the students skills or strategies for problem-solving. Jayne stated that often Pamela "was busy and said [to] ask someone else if they know [because] I can't really do it right now". This mental model contradicted videoed evidence of Pamela's interaction with the students, for example, during the time of the stimulated recall episodes in July 2005 (Chapter 5), where she constantly reviewed the problem-solving strategy of retracing steps with the students. Sam obviously remembered Pamela's involvement in this strategy as he made reference to it in his comments in the longitudinal interview as "going over what you've done" (Table 8.3).

Pamela's mental model of students using problem-solving strategies did include students "learning how to learn themselves" (Pamela, Post-Experience Interview, 5 September 2005). Her pedagogical practice encouraged independence. The skills she attempted to have the students develop included going "back and analysing what they've done and analysing where they're up to and where they've gone wrong" (Pamela, Longitudinal Interview, 16 March 2006). She continued to believe that one of the teacher's roles was to set students up as "successful risk takers and successful problem solvers" as this would allow the students to grow as learners. The application of this mental model into classroom practice encouraged students to use those problem-solving strategies rather than being told the solution.

Bree, Ellen, and Sam's longitudinal mental models have incorporated this pedagogical practice into strategic approaches to problem-solving (Table 8.3). Jayne, a dependent learner, relied on formulaic application of skills, knowledge, and processes, and was unable to incorporate effective strategies into her mental model of problem-solving. She was reliant on assistance from others when faced with a problem. Teachers, through close monitoring of each student's efforts to negotiate problem-solving situations, can ascertain which students may not have incorporated effective problem-solving strategies into their mental models for a domain. A challenging, discovery-based curriculum can provide many opportunities for students, like Jayne, to explore their problem-solving potential as long as their inadequate application of such skills has first been recognised through appropriate assessment strategies.

Metacognition

Metacognition is more than simply what we know of ourselves as learners. Royer et al. (1993) provided a succinct definition, as well as some helpful guidance, on the relevance of metacognition in learning. They saw metacognition as "one's capability of governing and being aware of one's own learning" (p. 226). Similarly, Henderson and Tallman (2006) considered control within their definition, that does embrace "thinking about our thinking", but supplements this action with "employing strategies to enhance and problem solve solutions when there is understanding failure" (p. 28).

The predictive (Johnson-Laird, 2006; Vosniadou, 2002) and diagnostic (Kyllonen & Shute, 1989; Royer, et al., 1993) functions of mental models are linked cognitively to metacognitive awareness. Royer et al. (1993) offered some useful strategies for developing metacognitive skills that begin with the awareness or diagnosis of what is already known. Once established, a learner utilises a variety of learning strategies that may vary, in order to match the demands of the task. This match requires the learner to use the prediction function of mental models (Johnson-Laird, 2006; Vosniadou, 2002) to judge the likelihood of the success of those strategies. Monitoring the success (or otherwise) is necessary before the learner can plan ahead to use the learning time available in the most efficient way. Most importantly to this study, Haycock and Fowler (1996) found mental models to be "a convenient mechanism with which to consider how we acquire knowledge, achieve understanding, and generalise problem-solving skills to make them available to different situations and develop metacognitive skills" (p. 28). Therefore, in order to fully investigate the importance of metacognitive awareness to how efficiently mental models are run by the participants, questions were asked during the longitudinal semi-structured interviews about what the participants believed they had learned about themselves as learners. This required them to reflect upon how they engaged useful strategies.

The students were asked to look back over the year spent working with robotics as the context within in which to consider what they had discovered about themselves as learners (Table 8.4).

Table 8.4: Student responses about what they had learned about themselves as learners.

Student	Responses
Bree	I'm not that good at learning things that I haven't actually done before. You could try and learn more about the subject before you do it.
Ellen	I learnt that sometimes it's good to work in a group. You can have different opinions. You can have yours and you can put them together, and that works. You learnt how to keep on going and you couldn't really stop. You've got to keep on going.

Jayne	In the end I just learnt how to build a robot. I felt good that I knew. I didn’t think that I’d be able to do stuff that I didn’t think I’d be able to do. You don’t really put yourself down. You just think you won’t be able to and you can.
Sam	I can do more things than I think I can. You can look back at it and you can say, “Well, I’ve done that so why can’t I do it again!” Could use it [the skills] for anything.

There is a significant thread that runs through each of the students’ responses that highlights the realisation that, with effort, things that seem unachievable are possible. Staying positive seemed to help Ellen, Jayne, and Sam while Bree recognised that it might be beneficial to do some investigation into the subject prior to starting the activity. Only Sam linked the things he had learned about himself as a learner doing robotics to other domains. This reflects a multi-dimensional, cross-contextual consideration of skills supported by Haycock and Fowler’s (1996) view of the generalisation of mental models. All of the students seem to acknowledge that they learned to keep applying the problem-solving skills or knowledge and processes that they had learned, in the belief that this application would enable them to overcome a failure in understanding (Henderson & Tallman, 2006).

Prior to their engagement with robotics, the students had a “model in their head of what learning should be and it’s not making decisions for themselves” and their mental models did not include “analysing their own thinking and analysing their own learning” (Pamela, Longitudinal Interview, 16 March 2006). She attributed these beliefs, that is, her mental models, to the way in which the students’ previous teachers implemented and assessed the curriculum; spoon-feeding the students rather than encouraging independence. Pamela believed that it was “hard work” for the students to “think for themselves” instead of “playing, ‘What’s in the teacher’s head’?” because being independent would require them to “actually look at what’s inside their own head!” Pamela stressed that the students had little training or experience to reflect this way. She believed that, “by the age of eleven, we’ve actually taken that [ability to be reflective] away from them” and the way to encourage this metacognitive practice of self-reflection is to “re-encourage them to be risk takers”. The opportunity to do this presented itself through robotics. As Sam said, “There’s nothing else really like robots!” (Sam, Longitudinal Interview, 17 March 2006).

In many ways, there were significant matches between the students' and the teacher's mental models of metacognition. They all acknowledged that learning is a difficult process when it requires active participation in the knowledge-construction process, rather than the passive acceptance of information in the knowledge-regurgitation process. The simplicity of using a problem-solving strategy, such as reviewing the steps taken so far, became complicated in the face of long-held attitudes created from experiencing an easy-to-digest, spoon-fed syllabus. Some students, such as Jayne, were extremely disconcerted by the requirement to start and to continue thinking and acting for themselves. Bree, Ellen, and Sam, enjoyed the challenge, while acknowledging its complexity and confrontational nature. The perturbation they felt enabled them to develop richer, more robust mental models of robotics, problem-solving, and metacognition: thus metamorphosing into equilibrium as they assimilated the new conceptual, declarative, and procedural knowledge into their mental models. They learned.

Mental Models of Assessment

Mental models serve many functions, including explaining the purposeful employment of conceptual, declarative, and procedural knowledge as well as predicting the likelihood of the success of that employment (Johnson-Laird, 1983; Norman, 1983). The mental models a student runs to select the most salient strategies are guided by a control functionality that entails finding the most suitable model-task match (Bibby, 1992) between action and result. The control functionality facilitates the elimination of redundant or unsuitable mental models as alternatives are considered during the exploration of possible options to find a satisfying result (Carley & Palmquist, 1992; Renk et al., 1994). In simple terms, if guided by effective teachers, students who engage in problem-solving activities should know when the product, that they produce as a result of their investigations and actions, is a practicable outcome of the running of their mental models. Students should also be capable of contributing thoughtful and realistic evidence of their own assessment through their engagement of mental models that serve an explanatory function.

When the students were interviewed in March 2006, the stability of the mental models they had exteriorised in the November 2005 group forum interview about assessment was investigated. Various probes were conducted during the interviews to establish their mental models of the types of assessment that were suitable, when assessment strategies should be communicated and implemented, and what can be learned by promoting a variety of assessment strategies with different students.

Types of Assessment

What types of assessment can be useful to determine the mental models held by students in particular domains of interest? Bree, Ellen, Jayne, and Sam were asked this question and they provided a homogenous response: students should have the opportunity to show what they can do (Table 8.5).

Table 8.5: Student responses about why showing what has been learned is a suitable assessment strategy.

Student	Responses
Bree	So the teacher knows how good [sic] you knew how to do it.
Ellen	So she [the teacher] can actually see what you're doing.
Jayne	So, if you weren't really that good, they [the teacher] could help you. To see how good we were.
Sam	Seeing if I'm reaching my goals that I'm putting in [sic].

The students have associated a teacher's assessment strategy of observing student performance with the opportunity to demonstrate how well they can apply their skills. Bree and Jayne refer to the teacher observing how "good" the application of skills and knowledge was, while Ellen focussed on a more global comment of observation enabling the teacher to determine what is "actually" happening in the application. This is the process of applying mental models. Sam explained the purpose of observation more definitively by incorporating the attainment of the student's "goals" as the purpose for demonstration. This inclusion indicates that he has linked his mental model of his goals in learning to the assessment strategy of observation because it enables a teacher to concentrate their focus on a particular target. Sam was the only student who discussed how assessment could also inform him, as a learner, of what goals he could achieve.

Pamela was also questioned as to the most suitable assessment strategies for general classroom learning as well as the more specific ones related to the robotics domain. Her responses to interview questions indicate that, while she believes there might be some differentiation between subject domains because assessment “depends on the task”, the most suitable assessment strategies are “determined early on [in the learning activity] by having the students looking at themselves”. She believed that they should “demonstrate to each other what they have learned before they actually bring in an ‘authority’.” That is, the teacher. This approach enables the students to work with peers to establish what areas still need some attention so as to refine their skills and adapt their knowledge: the act of being metacognitive. Stein (2004) supported this type of peer practice interaction and suggested that the provision of such opportunities for “meaningful dialogue” between students and between students and their teacher is necessary to promote learning (p. 5).

The students were also asked whether or not success in robotics equated to the successful completion of a robot product. Determining student competence by observing the completion of a final artefact is customary in education. Reeves (2000) cautioned that deeply-held conceptual knowledge within a domain may not be directly observable even in such a specific product as the robot. He suggested that such knowledge may only be inferred by observing students’ performance over time and with a range of tasks. Table 8.6 shows the students’ responses to inquiries about whether completing a task is an indication of successful learning. Their responses indicate some mismatches between their mental models.

Table 8.6: Student responses about whether completing a task means you have, or have not, learned.

Student	Responses
Bree	No. You could always try again. They [parents and teacher] should know that I try my best.

Student	Responses
Ellen	Not necessarily. If it was an easy test, you might say, “Why didn’t I finish it?” But then, if it was a really hard one, you’d think, “Well, I just did my best.”
Jayne	Yes. I might be a bit worried because it’s, like, you don’t know it and you might want to learn how to do it a bit more.
Sam	Then you failed. Maybe give you another chance to do it again.

The students' mental models mismatched. Bree clearly believed that non-completion does not indicate the absence of learning and suggested that having more attempts to show what can be achieved is a valid way of conducting assessment. Ellen was more pragmatic. She differentiated between the levels of difficulty that might be faced when undertaking assessment tasks and included a self-reflective attitude if the task was "easy". She rationalised the concept of "doing one's best" if the assessment proved to be more difficult. Jayne equated completion with learning, indicated by her clear affirmative "Yes!" to the question. Her response also indicated that she might be "a bit worried" because non-completion would show that she did not know "it" [robotics]. She substantiated this concern with a reference to metacognitive awareness that learning more might help her through the assessment more easily. While Sam proposed the possibility of having another attempt at an assessment task that was not completed, his initial response indicated some agreement with the "get it right/get it wrong" paradigm about which Papert (1980) expressed concerns within discovery-based learning environments. The students' responses were complex and their variety indicates that assessment is a problematic area of education for students.

Pamela was also asked questions about the requirement of students to complete assessment tasks for the demonstration of learning. She believed that it was critical to "have a flexible timeframe for actually allowing your assessment" in order to enable all students to demonstrate their capabilities. While she acknowledged, that it is important "to have strategic times that are set" for the regular implementation of an assessment strategy, this regime needed to "be flexible enough to give the students as many opportunities as they need to show you what they can do". Such a flexible attitude to assessment would encourage the development of positive attitudes to learning and the subsequent assessment of that learning. Positive attitudes are essential, Reeves (2002) proposed, so that students can develop and appreciate appropriate thinking skills. They also enable students to strengthen their commitment and motivation to develop problem-solving skills and to satisfy their "intellectual curiosity" (Reeves, 2002, p.104). Such commitment and motivation, to ensure that the skills and knowledge, that are of value, are pursued in learning activities and in assessment strategies, promote learner efficacy and a student's more realistic appreciation of their learning journey.

From the data collected in the longitudinal interviews, it would seem that Pamela's mental model of assessment type matched the longitudinal (March 2006) mental models held by both Bree and Ellen. This match was evident in the unanimous acknowledgement of the amount of flexibility around how many opportunities a student would be given to demonstrate their ability within a domain. Pamela's mental model of assessment mismatched those held by Jayne and Sam. Sam counteracted his initial "non-completion-equals-failure" comment by recognising that a further chance could be possible to show ability, thereby indicating a partial match to his teacher's mental model. Jayne clearly held a mental model that did not match with the other participants but she did acknowledge that a deficient capability would indicate an opportunity to learn more. Robotics does offer students the opportunity to give creative responses but the assessment of those responses should "cater to student diversity without compromising standards" (Saddington, 2004, p. 130). A complex activity should accommodate variables, such as, when students are given particular assessment tasks.

Timing of Assessment

Student diversity might require varied assessment instruments to meet individual needs. When questioned as to the feasibility of providing different timings for assessment tasks for different students due to wide-ranging ability, Pamela responded, "You need to give them multiple opportunities to show the same task in a range of different environments. So the pace that you actually set for the assessment is critical to the child's learning style" (Pamela, Longitudinal Interview, 16 March 2006). She continued, "Not every child is going to achieve every outcome" at the same time and that "being able to see the scope of their success is different for each child". Pamela regarded the pedagogical focus on students reaching a pre-established benchmark at a specific time was secondary to the importance of ensuring that students develop "feelings of success and the feeling of confidence" in learning. Pamela believed that students' learning journeys were different and that they "will come to different points [of that journey] at different times". This characterised her expectations that students would not all move along the learning or assessment pathway in the same way.

Pamela's learner-centred philosophy of assessment, while being very strongly held and clearly expressed in the interview, may not have been communicated quite so clearly to the students. While the students' mental models of assessment were formed over time and through their individual experiences in diverse classroom settings, they had all been exposed to a homogenous learning domain, robotics, that challenged them with perturbing, problem-solving situations. All four students had been in Pamela's regular classroom during 2005 where they had experienced learning, under her guidance. Even though Jayne and Sam had left to attend other schools in 2006, they had been part of the larger cohort of 54 who had experienced, first-hand, her approach to learning and assessment for a full academic year prior to the longitudinal, semi-structured interviews in March 2006. Surprisingly, the four students hold disparate mental models of assessment to Pamela and to each other (Table 8.7) although similar themes are evident.

Table 8.7: Student responses to questions: What if you needed more time to finish the assessment? Is it fair that students have different time limits for assessment? Should everyone be at the same stage at the same time?

Student	Responses
Bree	For the kids that haven't finished, it is fair. For the kids that have, it isn't, because if you're finished what can you do after it?
Ellen	If most of the class is behind, it is kind of fair. But if you're the only person, you've got to think, "I wasn't really quick enough if everyone else has finished." I think, have time limits longer than you expect[ed].
Jayne	It could be that they can't work as fast. If they haven't completed it, they might not be able to finish it and might get it [wrong] on their report card. If just might be that [some] people are a lot slower than other people.
Sam	Time matters. What if it's very little time and you've got to do a couple of things at the same time? I don't think everyone is on the same level all the time.

Given the questions, equity and fairness were major threads. The four students were inclined to substantiate their perceptions and provided three explanations as to why there might be different situations that required the consideration of more time: fair use of time; group time; and grading or ranking.

Bree's concern was less about the equity question of assessment and more about the "fair" use of time. She might have had experiences where she had to wait for others to finish and had no interesting tasks to work on while waiting. Ellen's solution to "have time limits longer that you expect[ed]" reinforces the concept of fair use of time being important in the assessment of ability and that “bonus time” could be provided by the teacher in order for students to complete the task. Ellen also introduced a construct of “group time”. She was the only student who considered a comparative view of class ability in relation to time taken for tasks, thus indicating a diagnostic functionality to her mental models in this area. While the variation in time taken to complete tasks may be difficult to accommodate in a classroom, it is the interpretation of the time taken that is of concern. While teachers, such as Pamela, might value the individual and their personal journey in learning, students, at least these four, are often judging themselves against others within the group.

Ellen’s mental model of assessment also includes some grading or ranking constructs because she included an awareness statement that “I wasn’t quick enough” if the rest of the class is finished. Jayne’s responses acknowledged the difference in the time it takes different students to complete tasks; this appears to be a frank observation that some students are slower at completing tasks than others. Time mattered, said Sam, particularly if there was little time and much to be done. He also acknowledged that students may have differing capabilities.

This paradigm of ranking and judging has become a predominant theme in our society through the use of competition and the assignation of labels, such as first, second, and last. We might value everyone’s contribution to sport, music, and the arts, yet we award prizes to those who perform better, by some criteria, than others. Teachers, such as Pamela, have a nurturing yet political role in ensuring a learner recognises their personal strengths so that they can overcome the tendency to rank themselves against others.

Jayne’s reflections are of interest because of previously expressed concern with how others perceive *her* personal learning accomplishments. This was articulated through comments about how unsuccessful attempts would be included on a report card. Jayne’s mental model of learning incorporates the perception of success by others and this mental model has remained consistent throughout the study (Chapters 5, 7 & 8).

It was evident from the responses that the timing of assessment strategies was of concern to all participants in the study, regardless of the match or mismatch of the mental models of assessment. If the issue of timing influences the variety of assessment strategies, how do teachers communicate the validity of these variations to those who are involved in assessment matters?

Communication of Assessment

The participants in this study were questioned as to the importance of knowing what assessment strategies were going to be used to measure the learning journey they had undertaken. Their responses indicated that the mental models of communicating assessment purpose and method matched each other. This consensus may have been influenced by the mismatch of the communication of assessment strategy that had occurred in the robotics activity in 2005 (Chapter 6). The students were asked if it was important to know, in advance, what the teacher was looking for when they were being assessed. All agreed that it was essential to have this knowledge, but disagreed on how frequently this information was, in reality, communicated to them (Table 8.8).

Table 8.8: Student responses to question: Do you understand what the teacher is looking for in an assessment item?

Student	Responses
Bree	Yes. You can improve on what she's [the teacher is] marking. You can know what to work on and what not to work on.
Ellen	Yes. They [the teachers] should have a criteria sheet on how you should do it. They [the teachers] should explain it to you before you do it. Then they [the students] know what they're aiming for.
Jayne	Yes. It would help because then you know what you could show, or how you have to act, for what she [the teacher] wants to see or know.
Sam	Yes. She [the teacher] would have results from the whole thing and not specifically what she wanted. I could focus on it a bit more.

Decisions are made by students about how they will respond if the assessment purpose and content are clearly communicated to them. Bree and Ellen agreed such clear communication of the purpose and content of the assessment strategy would enable them to "know what to work on" or "what they're aiming for". They agreed that some specificity of process, and possibly product, should be included and communicated. Jayne suggested that having such knowledge would enable her to know "what to show" and Sam proposed that having knowledge of assessment purpose would enable him to "focus" on what was needed to complete the task.

Criteria sheets may influence the effort applied to completing assessment items. Jayne, with her propensity to provide more detail, believed the criteria sheets given by teachers were useful because “you look at what mark you’re hoping for, where you think you’re going to get, and then you know what you have to achieve to get that mark”. Her response indicates that some level of decision-making might occur when students use criteria sheets to pre-determine what effort they apply in order to achieve a selected level of competence. Such criteria sheets or rubrics, designed to enlighten interested parties on the performance required to achieve a pre-determined grade, may not be producing the holistic assessment intentions that were envisaged by the teacher.

Criteria sheets can explain the purpose and content of assessment. However, if used by students to predetermine effort, they may also influence the teaching styles used in classrooms (McLaren, 2007) by invoking the pedagogical practice of “teaching to the criteria sheet” rather than “teaching to the test”. Kalantzis, Cope and Harvey (2003) proposed the need to develop appropriate assessment that recognises creativity and problem-solving rather than limited curriculum measurement strategies that judge right and wrong responses or right and “more” right responses, such as criteria sheets. Using the word “criteria” in a slightly different way, Moreland, Cowie and Jones (2007) suggested that criteria that address the negotiation of success in learning should be displayed in classrooms thereby providing coherency in the design of assessment strategies and the communication of that coherency.

The concept of individual student success, or improvement, was mentioned by Bree. Her mental model of assessment includes a modicum of “learning for the test” paradigm, but a more favourable interpretation of her comment about “improving” in a particular domain could signify a diagnostic purpose. This diagnostic functionality of communicating assessment purpose and content is important, because it would enable the students and the teacher to have discourse about the intentions of the learning experience and the goal of the assessment strategy (McLaren, 2007).

The opportunity to reflect on the learning that has occurred, through some dialogue between students and the teacher, can clarify the purpose of the activity and aid the development of authentic strategies that effectively gauge current learning while promoting life-long learning (Petrina, 2000). Unfortunately, the communication of the content and purpose of assessment strategies is not always effectively achieved in classrooms, and this lack of clarity became evident when the students were questioned further about their general, classroom assessment experiences.

The students' mental models of the purpose of the assessment instrument applied by any teacher showed that Bree and Ellen agreed that they did not always know the purpose of the assessment task or what content it was attempting to measure. While, in general, Ellen proposed that knowing in advance could help to complete the task effectively, Bree was more forthright and stated that not knowing was "like a shock because sometimes you don't work on what she's [the teacher is] marking" This lack of knowledge caused Bree some distress and she felt "angry" that she may not get the result that she wanted or deserved. In contrast, Jayne and Sam agreed that they usually do know what the assessment tasks are attempting to measure; a clear mismatch to the other students.

When questioned about her mental models of clearly communicating assessment strategies and their purpose, Pamela emphasised the criticality of students having unambiguous knowledge of assessment. She agreed with the students that they need to know what assessment will be undertaken "before they can even start" so they "know the journey that they have to take and what it is that they're going to be assessed on". Pamela stressed that "clarity [of assessment] builds a platform of success" for the students and that, if "assessment is done well, and it's done in a positive way, the children can use it as a springboard onto the next series of activities" (Pamela, Longitudinal Interview, 16 March 2006).

Pamela's mental model matched Bree's by using assessment for guiding improvement in capability. This was proposed through students having an opportunity to "determine some of that [the learning journey] themselves". This mental model is supported by Pintrich and Schunk's (2002) description of a mastery-approach goal orientation where the learner has the opportunity to predetermine their goals and standards and therefore aim for self-improvement in the learning process. This mental model requires teachers having the confidence to "go outside what has been traditionally done" in assessment tasks in order to meet the needs of the individual student and the type of learning they are experiencing. This proactive decision-making would involve various assessment being in the hands of the students that would afford them "the power to make decisions about where their learning is heading" rather than something that is totally "teacher-directed" or, at its worse, system-directed. This focus was proposed by Saddington (2004) who suggested that assessment that provides the opportunity for creative and varied responses will help to cater for the diversity of learners without standards being compromised.

Jonassen (1995) advocated that assessing learning is best done by understanding the learners' mental models used within the domain to solve problems. Indeed, such assessment practice may enhance the standards while working to inform their validity through the reality of individualised assessment meeting individualised instruction. Barker, van Schaik & Hudson (1998) proposed that mental models can be effectively used in such situations, to both enhance assessment strategies as well as assisting in the diagnosis of the learning journey being undertaken.

Mental Models: What Can We Learn?

The longitudinal aspect of this study enabled the participants to contribute much more to the understanding of how mental models are activated, stored, and modified in learning and assessment. Investigations conducted one year after the commencement of the robotics activity in March 2005, and three months after the student participants had engaged with the robots for the last time in December 2005, enabled them to stand back from the whirl of involvement in order to respond with robust mental models on a variety of teaching, learning, and assessment topics. Learning, and the assessment of that learning, was a major focus of the longitudinal investigations because how students perceive the success of their journey can contribute to a richer understanding as to how an understanding of mental models can be used to design, develop, and assess pedagogical practices in classrooms.

The complexity of mental models of learning and assessment can be understood by investigating how students perceive what can be learned about themselves as they undertake both learning and assessment activities (Table 8.9; see next page).

Table 8.9: Student responses about what can they learn about themselves when completing assessment tasks.

Student	Responses
Bree	I learn that I'm not as good at it as I think I am, so I've got to learn it. I can crack under pressure and then I get all angry at myself.
Ellen	You probably learn how you work best. If you have a choice, you can work with a partner, or work by yourself. You know how you work best.
Jayne	You keep thinking, "I'm not going to be able to do this," and you do it. You just think, "Oh, I didn't think I'd be able to do it." You learn something you didn't know about yourself. If you're given something that's a bit similar to it, you'd know that you'd be able to do it.
Sam	You know how to do that, if you weren't sure about it beforehand.

Responses were varied and five key issues were illuminated through students' responses: cognitive assessment has affective consequences; individual or social constructivism should be considered in self assessment; generic skills can be transferred; assessment provides affirmation of learning; and the recursivity of students' mental models.

The first issue is that while students undertake assessment of cognitive processes there are affective consequences. Bree's response indicated that is convinced she is "not [be] as good as I think" (Table 8.9). Her mental model has the potential to debilitate future engagements in assessment activities if she also incorporates the negative affective domain that holds her cracking "under pressure" when faced with a challenging task that is also being assessed. Her inclusion of the feeling of "anger" at herself is of concern when compared with the "celebration of learning" envisaged by her teacher, Pamela. Henderson and Tallman's (2006) and Royer et al.'s (1993) research suggested that a teacher needed to identify the nature of the mental models with which a learner is operating because an incorrect or flawed mental model may require specific intervention. Bree's mental model incorporated the emotional stress of challenging tasks with pressure to perform. Strategies to deal with the pressure of such occasions should help overcome the controlling nature of such stultifying mental model enabling activation of procedures that promote confidence.

The second issue is the consideration of individual or social constructivism in self-assessment of learning. Ellen's mental model included deliberation of a preferred learning context. While she had been uncertain as to whether the robot she would construct in a group would be better than the one she made on her own (earlier in this chapter), she acknowledged that working with others enables ideas to be shared. Ellen was controlling her mental model of learning by consideration of working individually or in groups that demonstrates that she is both comfortable in either learning situation and confident of communicating this differentiation. Assessment tasks were seen as opportunities to learn about how she — and any other student — worked "best".

The third issue raised by the responses is the transfer of generic skills. Jayne's responses to the questions of learning about herself through assessment provided some insight into her otherwise formulaic mental models of working in problem-centred domains, such as robotics. Jayne acknowledged that you "learn something you didn't know about yourself" and that this knowledge could be applied to other areas that were "a bit similar". The application of knowledge in this way demonstrated her holistic application of conceptual, declarative, and procedural knowledge, indicating the predictive nature of mental models and how associated application of knowledge can contribute to learning across the curriculum. Her responses indicate Jayne's cognitive growth since her Teach-Back and Focus Group experiences (Chapter 7).

The fourth issue raised concerns the self-affirmation of learning. Sam's responses, while simplistically stating that assessment provides some certainty as to a student's application of knowledge and skills, clearly demonstrated a self-awareness that gains clarity when assessment strategies are used to determine learning. His response echoes Norman's (1983) view of mental models, as being "what people really have in their heads and what guides their use of things" (p. 12), because the establishment of success determines how skills and knowledge could be used by the individual in subsequent experiences.

The fifth issue relates to the recursivity of mental models (Power & Wykes, 1996) and how students can differentiate their activation, to provide problem-solving capability, as well as self-reflection, in order that they can understand themselves and how they apply successful learning strategies. Ellen's response that states, "You know how you work best" provides a summary of such differentiation of effort and the accompanying self-understanding.

This recursivity of the students' mental models (Power & Wykes, 1996) was also affirmed through Pamela's 2006 interview response to probes concerning her 2005 assumptions about students' mental models of self-learning during assessment. She observed they had had a positive attitudinal change when asked to assess their personal learning journey. She ascertained this positive attitudinal change from their weekly 2005 self-reflection journal entries of their robotic challenges and successes by recording their goals and achievements. Pamela believed that such reflective record keeping strengthened their appreciation of how and when they applied successful strategies. Setting their own goals and evaluating the success or otherwise of effort encouraged them to "see themselves in a completely different light" — something Pamela observed they had not experienced prior to the robotics activity. Pamela believed that they would, therefore, see evidence of their ability to "take on challenges and work with those challenges" that would lead to success in future activities.

Pamela's mental model of what can be learned through assessment did not completely match those of the students although some of the students' comments reflected key elements. It was expected that exposure to Pamela's pedagogical practice would influence the students' mental models and this was somewhat evident in the mental models they had exteriorised during the interviews, through their reference to collaborative learning experiences and awareness of the knowledge and skill attainment.

Each person is on an individual learning journey. This belief was a clear match among the participants' mental models. During the longitudinal interviews held in March 2006, Bree stated that "we all learn differently" while Ellen acknowledged that "some people like to write and some people are better at doing [things] physically". Jayne believed that "not everybody's the same" and Sam stated that "we're all different people". Pamela summarised this individuality clearly with her comment, "no one learns at the same pace. No one learns the same things. People will pick up different things at different times".

The individual journey also causes perturbation, particularly if it also involves the students accommodating novel pedagogical practice. Pamela acknowledged that she had become "more learner-centred" throughout the project and had, subsequently, "handed over some of the control to the students". She found that the students, themselves, were at various stages of readiness to take the reins of that control. Pamela understood, and the students grew to realise, that they were moving from an environment of spoon-fed curriculum delivery to one in which they were obliged to take a more active role in determining their own learning journey, albeit with guidance from her.

Pamela observed throughout the experience, in her journal on 27 July 2005 and during the Post Experience Interview on 5 September 2005 that the change to active learning was discomforting for some students. She reflected that the 2005 cohort of students "had a model in their head of what learning should be and it's not making decisions for themselves and analysing their own thinking and learning" (Pamela, Longitudinal Interview, March 2006). She hypothesised that the students had arrived at this way of learning by being exposed to teachers who had a narrow way of teaching and assessing them and that it was "hard work for them [the students] to actually think for themselves". This narrow interpretation of the curriculum and use of systemic assessment had denied students the opportunity to become reflective "risk takers". She explained that her pedagogical change was a challenge for the students but that it was her responsibility to "break those barriers [to learning] down" even if "it's [change is] quite painful for them!"

Robotics had provided a new domain for both Pamela and her students to experience self-guided learning and hands-on problem-solving. Robotics had promoted new ways of teaching for Pamela, learning for the students, and assessing the learning journey travelled for all participants.

In Summary

Quite possibly, students and teachers do not possess the mental models that are required to operate confidently and successfully in the problem-centred environment proposed by Pamela. A way forward might be to establish exactly what mental models are being used at the beginning, in the middle, and at the end of a planned learning experience. The very nature of the classroom environment created by teachers, and used by all members of the class, may be inhibiting the creative responses that are required to negotiate both modern curriculum and life outside the classroom. Mental models are the tools we use to understand, seek alternatives, and make choices in dealing with our world (Henderson & Tallman, 2006). When we are faced with problems, such as creating authentic teaching, learning, and assessment environments that foster creativity in problem-solving, then we must retrieve and/or create the mental models that will enable us to understand the alternatives available to solve the problem (Johnson-Laird, 1983).

When Bilbo Baggins neared the end of his journey, the wizard Gandalf turned to him and stated, "'My dear Bilbo!' he said. 'Something is the matter with you! You are not the hobbit that you were'"(Tolkien, 1937, p. 277). The change that occurred in the mental models of the participants in this project was the way they perceived the role they played in negotiating their own journey and interacting with the environment. Like Bilbo, the participants in this research, including the researcher, were on an adventure in which they discovered more about themselves and how best they travelled along their learning pathways.

CHAPTER NINE: *Longitudinal Mental Models (October 2006)*

"They were at the end of their journey, but as far as ever, it seemed from the end of their quest" (Tolkien, 1937, p. 190).

Introduction

The participants in this study were also nearing the end of their journey but would also be on an individual learning journey into the future. This part of the journey saw a reduction in the number of participants, not through combat with trolls or dragons as occurred in *The Hobbit*, but through the taking of different forks in the road. Jayne and Sam had moved to other schools in January 2006 and were no longer participating in the final longitudinal aspects of the study in October 2006.

Bree, Ellen, and their Year Six teacher, Pamela, provide the data for the final aspect of the last research question: In what ways have the mental models of teaching, learning, and assessment managed the participants or been managed by them, longitudinally? This comparatively short chapter presents a critical summary of how the students, Bree and Ellen, and Pamela, used mental models to store information (O'Malley & Draper, 1992; van der Veer & Peurta-Melguizo, 2002) and problem-solve (Johnson-Laird, 1983; Newton, 1996) so that they could function in a novel learning situation, such as robotics.

It will explore three themes to explain how the three remaining participants used mental models created and stored in long-term memory (a) to link information in innovative and personalised ways, (b) find solutions to the problems they had encountered, and (c) continued to encounter along their own learning journey. The chapter further demonstrates how mental models, while complex and inherently epistemic (Jonassen, 1995), provide a platform from which students and teachers can express what they know.

A Longitudinal Case Study

This longitudinal aspect, taking place 20 months after commencement of the project in March 2005, involved interviewing three of the original participants on 30 October 2006. In the intervening seven months, the two students, Bree and Ellen, had been taught by two different Year Seven teachers who used traditional, behaviourist pedagogical practice. This pedagogical practice was significantly different from that which they had been exposed in Pamela's class in 2005. Neither Bree nor Ellen had been involved with robotics activities during 2006. Both students had undertaken the state-wide Literacy and Numeracy standardised tests for Year Seven students in August 2006, two months prior to this interview. During this Post Robotics interview, Bree and Ellen acknowledged that considerable class time over several weeks had been given to preparation for the tests. While the determination of the influence of their educational environment is beyond the scope of this study, this research sought to understand the impact such a rigid focus on testing might have on their mental models of teaching, learning, and assessment.

The thirty-minute interview (Appendix Q) with the two students, Bree and Ellen, took place at the school in an empty classroom during non-class time where one teacher, not associated with the project, was present but not within hearing distance. The interview was a paired, semi-structured interview where both students responded to questions and included specific questions about their experiences with robotics in 2005 and generic, non-robotics', questions about teaching, learning, and assessment experiences in their current Year Seven class. Pamela's individual, semi-structured interview (Appendix R) was held out of school hours.

Interview Methodology

The prime advantage of conducting a paired semi-structured interview is gaining distributed cognitive mental models. Bree and Ellen appeared, at times, to be creating a shared mental model through successive contributions to a particular prompt. They were actively engaged in distributing their cognitive structures between each other and across a topic. An example of this was where the students had been asked a generic question, rather than a robotic-focussed one, about planning for research (Table 9.1) on the major project they were completing at this time in Year Seven.

Table 9.1: Student responses about planning for research.

Interviewer	Do you change things or do you do you follow what the teacher says?
Ellen	You may change it.
Bree	You make your own plan.
Ellen	Your own design.

The students are building a shared mental model that incorporates each student's mental model of the idea of "planning". The picture they created involved the real possibility of changing the teacher's plan (Ellen) to make your own (Bree) that was of your personal design (Ellen). Using a similar context, to how they had learned, was another advantage. Sharing the interview was key to replicating the situated-cognitive environment (Brown et al., 1989) in which the mental models were formed in the first place; pairs of students solving problems. All previous data collection episodes, except for the Focus Group interview in November 2005 (Chapter 7), had been individual.

One disadvantage revolved around the influence of "groupthink" (Babbie, 2007, p.309), a phenomenon already explored during the discussion about the Focus Group Interview (Chapter 7). Another concern was monitoring the flow of ideas while following a prepared interview outline. The nature of group dynamics affect the flow of the distribution of ideas (Watts & Ebutt, 1997) and may make it difficult for the interviewer to follow interesting thoughts contributed from one individual (Cohen et al., 1995) or not gain responses for a probe from all participants. This is less of a risk in a paired interview where only two participants are involved because keeping a mental or written record of responses is achieved easily, particularly if an outline of the interview has been prepared (Appendix Q).

These interview considerations were important, particularly at the end of the study, where there were no opportunities to revisit the students once it was finished. The effectiveness of the joint or shared interview, to contribute to the data required by the research, is controlled by the interviewer who must remain focussed, yet patient, when guiding the discussion.

This chapter presents an analysis of the participants' mental models of (a) learning with robotics, (b) learning through problem-solving, and (c) assessment. It provides a unique longitudinal view of how mental models manage participants or are managed by the participants on their teaching, learning, and assessment journey.

Teaching and Learning with Robotics

The cessation of these students' engagement with robotics was due, in part, to the lack of resources to provide sufficient equipment for concurrent classes to be involved in the activity. The teacher, Pamela, also observed that two other reasons the study participants, now in Year Seven, were not continuing with robotic activities, was due more to the “lack of motivation of the [Year Seven] teachers” and “a lack of confidence, too” (Pamela, Longitudinal Interview, 30 October 2006). So, while, Pamela and her new cohort of Year Six students were engaging with robotics in 2006, Bree and Ellen were now in robot-free classes.

This 11 month disassociation with robotics may have curtailed the mental model goals the students had established in 2005 so they were asked what programs they would have liked to have completed with robotics, if given the opportunity. This question was important because it sought to return the students to their robotics experiences and the goals they had established for themselves. Bree stated that she would have liked to have finished the entire program as she only “got up to the second last one”. Ellen “would have liked to have built a double one because [she] didn’t get to do it and lots of people did”. Both students felt that they did not have the opportunity to achieve their final robotics goals.

Pedagogical practice – teaching robotics.

Bree and Ellen had gained some expertise in robotics during 2005. Their longitudinal mental models of how to teach it to others would provide some data to compare with the components and influences on pedagogical practice that had been obtained during the Teach-back episode in October 2005. They were asked how they would teach robotics (Table 9.2).

Table 9.2: Student responses about teaching robotics.

How would you teach robotics?	
Bree	Ellen
You know how we have the kits, I would put the kit on the ground and show them the parts and give them the information on the computer. I’d get them to read the information.	I’d show them the right and the wrong [methods] so then they learn. And then you’d do it on one computer and you show them.
Then they can make it and, if they didn’t make it properly, I’d help them. Show them where they went wrong so they can make the robot do what it’s meant to.	Get all the students around and then show them. And then once you’ve done that, you could show them the wrong part and what it does. And then they could do their work.

Bree's responses (Table 9.2) delineated the students' viewing the robotic kit's parts and allowing the students to both read the relevant information and make the robots. It was learner centred. She would "show them where they went wrong" if they made an error. Her mental model of teaching robotics is consistent with that exteriorised in their Teach-back episode in October 2005. One year later, her responses reveal that her mental model of teaching robotics is being managed by her and has remained stable with its inclusion of a hands-on, learner-centred pedagogy.

Ellen included a "showing" component that differed to her previously run mental model of teaching that had focussed on a hands-on, guided approach to learning robotics (Chapter 7). Ellen has modified her mental model of teaching robotics to now incorporate two elements: demonstrating errors and group demonstration. These modifications demonstrate that mental models can metamorphose in response to environmental phenomena, perhaps a current teacher's pedagogy, that require the creation of more usable mental models (Norman, 1983) to accommodate that pedagogy.

Ellen's modification of her mental model, that included the detailed step of showing the "right and the wrong" way of doing robotics, was of interest. When Bree and Ellen were questioned further about the efficacy of showing the "wrong" way of doing something, Bree suggested, "Then you wouldn't do the way that she showed you not to do it." This demonstrates that having this knowledge could be just as beneficial as having the correct procedural knowledge. Ellen's mental model now included the belief that "people learn from their mistakes, so the teacher can show you a mistake that you can do and you could probably learn from not to do that [sic]", meaning that you would pre-cognise an error. Perhaps their current teachers used show and tell and copy, or, do not copy techniques in their pedagogy.

Pamela, Bree and Ellen's teacher in 2005, deliberately did not include a demonstration component of the incorrect way of doing tasks in her pedagogical practice. This exclusion was due to her mental model where "you learn more from your mistakes than you ever do from the things you do correctly". Nevertheless, Pamela stated that her pedagogical practice included monitoring the groups who were working on robotics to see if any generic problems arose, such as the glitch that was evident in one programming exercise (Chapter 5), as this would indicate that the whole group required a demonstration of the correct procedure to get past that particular problem.

The environment and experiences created by pedagogical practice influence the activation and/or creation of and/or change to the mental models of students (Barker, van Schaik, Hudson, et al., 1998). After describing how they would teach robotics, Bree and Ellen were asked to reflect on what particular pedagogical practice of Pamela's, in 2005, had influenced their learning in robotics. Ellen responded to the question with an answer with which Bree concurred. She stated:

> She [the teacher] showed us how to do it. She wasn't afraid to help us but she didn't tell us how to do it. She gave us hints and we had to figure it out. It was problem-solving (Ellen, Longitudinal Interview, 30 October 2006).

This was a very powerful statement as it included cognitive, psychomotor, and affective domains of learning (McInerney & McInerney, 2006).

The cognitive domain is evident in Ellen's description of the problem-solving strategy for the learner. Ellen also referred to the psychomotor aspects of learning by referring to Pamela's hints. These hints or clues would lead the students to find solutions by selecting physical actions to take in conjunction with the relevant problem-solving cognitive functions.

Ellen also attributed the affective domain of learning to Pamela's teaching by including Pamela's willingness to give assistance. She indicates her understanding of the control or management that teachers apply to step back from the propensity to interfere with too much help for students as they attempt to negotiate problems. Even if this conceptual understanding was affirmed in Ellen's mental model of teaching robotics from experiences in other domains of learning and with other teachers, particularly in the intervening period. Ellen registered these processes as "problem-solving" strategies. In this way, Ellen was able to link the three aspects of learning very clearly in her succinct response to the question on how Pamela's pedagogy had contributed to her learning in robotics.

While Pamela's responses to questions about her pedagogical practice during the robotics experience were epistemologically more complex, they matched the response given by Ellen and supported by Bree. This mental model match indicated that the students continued to discern Pamela's pedagogical approaches and attach substantial educative value. Pamela confirmed her mental model of teaching incorporated learner-centeredness within discovery-based contexts by her comment "my goals are *still* to make them [students] into independent problem solvers". She found that "robotics is a great platform for it [independence] because of the nature of the program and the fact that it is fairly open-ended". Her approach required students to develop the "awareness that it's okay to fail at something and have another go" without seeing the teacher as the one who has, and should supply, all of the answers. Ellen may well have said that Pamela was not afraid to *not* help them because it takes even more self-discipline and commitment to stand back and let students fail at something rather than stepping in to remediate too early in the learning process.

Pedagogical practice – what can be learned?

Mental models enable learners to engage in self-reflection (Barker, van Schaik, Hudson, et al., 1998; Henderson & Tallman, 2006) that encourages them to challenge those very mental models (Senge, 1992; Szabo, 1998) through metacognitive understanding. What the students had learned about *themselves* from doing the robotics activity was established at several points in the study (Chapters 6, 7 & 8). Self-learning was visited again during the longitudinal interview in 2006 because it offered students an opportunity to express their metacognitive awareness. Ellen was the first to respond (Table 9.3).

Table 9.3: Ellen's responses to questions about what she had learned about herself.

Interviewer	What did you learn about yourself as a learner and how you learn from doing robotics?
Ellen	That I'd rather learn in a group because I understand myself more and they can help me.
Interviewer	How do you understand yourself more?
Ellen	Because they [other students] help me understand things and I understand that it's okay to ask for help and don't be afraid.
Interviewer	And was that an important lesson for you to learn?
Ellen	Yes, because later on in life you're going to need it because, if you're somebody's boss and you don't know how to do something, and they ask you, you just go, "What am I going to do?" You could ask *your* boss!

Ellen associated her learning in robotics with the social constructive domain evident through her stated preference of working in a group. She also understood that this style of working contributed to richer metacognitive awareness. She had learned to overcome her fear of asking others because they may interpret the seeking of help with incompetence. She realised that it was "okay" to ask for help when it was required and distinguished the importance of this learning by describing how the need to seek help could be applicable in the workplace.

While we may not be aware of the environmental stimuli that prompted Ellen to create this mental model of what she has learned through robotics, it is clear that this is an individually-held, idiosyncratic mental model for which she has created networks of other mental models meaningful to her. Her previously held mental model, determined six months earlier in March 2006, had also included the benefit of working in a group situation where “you can have different opinions. You can have yours and you can put them together [with others] and that works" (Ellen, Longitudinal Interview, 17 March 2006). But, in March 2006, her mental model had also included cognitive dimensions, such as, being persistent and the benefits of “keep[ing] on going” through challenging problems. This autonomous (Henderson & Tallman, 2006) aspect of mental models demonstrates their facility to map (Schwamb, 1990) experiences and highlights its non-arbitrary nature (Halford, 1993).

Bree was also asked the question about what she had learned about herself (Table 9.4).

Table 9.4: Bree’s responses to questions about what she had learned about herself.

Bree	I don’t really know. As I said before, there’s so much [sic] bad things about working by yourself and so many good things about working by yourself.
Interviewer	But this is just about working with robotics.
Bree	Yes.
Interviewer	Not about the group work but just doing the activity, robotics. Whether it was on your own or in a group. What did that experience teach you about yourself?
Bree	Um, because we had to work in a group and I had to work with two boys that I really don’t like. They kept talking about what they did on the weekend, what happened. I was the one doing all the work and it was like, I asked for them to help me and they went, ‘No, we’re too busy talking.’ ‘Will somebody please help me?’ So, I don’t really know.
Interviewer	You don’t know what you learned about yourself?
Bree	Well, I learned that I can be a bossy person! I can be.
Interviewer	Is that all right?
Bree	Yes. The way I’m talking about it, it’s, like, if they don’t help me the first time, I start to nag them, and people don’t like that!

Bree’s initial response includes her experiences of working in a group in the robotics activity. It had been established, during her post-experience interview on 6 September 2005, that Bree’s mental models “perceived” this style of working as both confrontational and detrimental to her progress in learning. Here, one year later, she may have been influenced by Ellen’s comments moments before. A more likely explanation emanates from her comment, “We had to work in a group”, because it shows the connection between her mental model of robotics and her mental model of group work: it shows what can be learned from robotics. Even when the interviewer had clarified the question (Table 9.4) to focus Bree on her mental model of assessing her learning style, she ran these two mental models simultaneously. Her response, therefore, did not correlate with the mental model of self-learning she had exteriorised during the 17 March 2006 interview where she had responded by saying, “I’m not that good at learning things that I haven’t actually done before. You could try and learn more about the subject before you do it” to the question of what she had learned about herself.

Bree’s unsatisfactory experiences in groups for learning at school were evident in many of her responses and a discussion, later in the interview, demonstrated how her mental model of group work was infiltrating many aspects of her mental model of learning. Bree explained that her Year Seven teacher, in 2006, required the students to write in an in-class journal each week. Bree had used her in-class journal to draw attention to her difficulties in group work. The teacher offered help that Bree accepted and some arbitration had been attempted. This attempt at remediation was a clear example of how providing regular, structured opportunities (e.g., Journals) for the communication of mental models can assist students with the various domains of learning. Following the intervention, Bree still retained a prevailing association between her failures to negotiate successfully in a socially constructed activity, such as robotics, with the actual learning experience of robotics in her mental model, as evidenced by her responses in this interview.

Another thing students learn from doing robotics concerns the process versus product pedagogical question that became evident in Pamela’s response to probes during her interview:

> They’re confident to have a go at new things that they have no knowledge of. They’re confident that they have the answers and, if they don’t have the answers, that they can find them. They are much more confident with the interaction between the programming sides of things; that they understood the language of programming much more. Their social outcomes are really

> staggering. They're much better problem solvers and they attack problems differently (Pamela, Longitudinal Interview, 30 October 2006).

Pamela's lack of reference to the completion of a product, such as a functional robot, was evidence of her managed and consistent mental model of learning. All of the learning outcomes were attributable to the individual student's learning journey, including the development of confidence, a willingness to persist, effective problem-solving strategies, and their productive social behaviours. The only specific cognitive construct to do with robotics was her inclusion of the "language of programming" that could, in fact, be attributable to any computer domain.

It would seem that in the areas of learning in robotics, with reference to social construction and problem-solving, there are some matches between the mental models of these three participants. These matches promote the functionality of mental models because there is less likelihood of communication difficulties arising between the teacher and students if the mental models are running simultaneously and in synchronicity. However, the mismatch of the social construction mental model held by Bree, with that expressed by Pamela, is of prime concern due to its longitudinal pervasiveness to affect her mental model of learning. Bree has continued to be managed by this mental model because successful, socially-constructed engagements at the time of, and subsequent to, the robotics learning experience have not been experienced and incorporated into her mental models.

Learning Through Problem-Solving

Much of the literature on mental models involves discussion concerning their fundamental role in solving problems (e.g. Anderson et al., 1996; Barker, van Schaik, Hudson, et al., 1998; Johnson-Laird & Byrne, 1991; Norman, 1983; Preece et al., 1994; Sasse, 1997). A definitive characteristic of mental models is their runnability (Carroll & Olsen, 1988; Henderson & Tallman, 2006; Norman, 1983; Young, 1983) and it is during the running of a mental model that a learner is interrogating their world to source a solution. Relevant mental models are retrieved, run, and adapted by the creation of mapped relationships to other mental models associated with the probable, effective completion of the task. Redundant components of mental models, or the redundant mental model itself, are eliminated in response to the mental model-task match made by the learner (Bibby, 1992). The richness and/or stability of the retained mental models increases through each subsequent running (Barker, van Schaik & Hudson, 1998; Preece et al., 1994) because only those mental models that remain individually valid, even if personally detrimental, such as mental models for smoking, are stored in long-term memory (Canas & Antoli, 1998; Gentner & Stevens, 1983; Henderson & Tallman, 2006; Norman, 1983) for future use.

The opportunity for learners to create such rich mental models is best fostered in authentic constructivist learning environments where the goal of constructing knowledge, that promotes the performance of problem-solving strategies, can be transferred to real-life tasks (Jonassen, 1995). The participants, in this study, operated in such a learning environment and the investigation of their mental models, one year after the cessation of the robotics activity, was able to shed light on how efficacious was the development of useful problem-solving mental models (Table 9.5).

Table 9.5: Students' mental models of the importance of problem-solving skills.

Interviewer	Ellen, are problem-solving skills important to learning?
Ellen	Yes, because you're going to use them later when you're working. If you have to pay people, and you pay them the wrong thing, you have to see if you can get it back and pay them the right amount.
Interviewer	What about while you're at school?
Ellen	Yes, because you learn. You learn to problem-solve. Like, not to just do it by the book. You learn to problem-solve.
Interviewer	Bree, do you use problem-solving skills at school?
Bree	Yes, because, say, if there's a bunch of friends that like you and there's another bunch of friends that don't like the other friends that like you, you'll have to choose a day to play with them and another day to play with the other people.
Interviewer	That's problem-solving?
Bree	Yes.
Interviewer	So problem-solving is not just about doing a sum? Or, how many litres of paint you need to paint a wall? Is problem-solving something else?
Bree	Well, that's also problem-solving. That way would be, like, with maths.
Interviewer	So when do you apply these problem-solving skills?
Bree	When you leave school and get a job, you'll have to work out what you need to do and how much you get paid.
Ellen	And you can use them in school, too, as in: it could be with friends, it could be the maths, it could be all sorts of things. You could have a maths problem, too, and you have to problem-solve that.

The students have extrapolated their mental models of problem-solving in two contexts: outside school and inside school.

First, Ellen is linking the use of problem-solving skills to a real-life situation outside of school; a work-place situation for which she might have had no direct experience but with which she has made a specific link to in her mental model of problem-solving strategy application. This link could have developed from a discussion at home with her parents or through interactions in her current classroom. The association demonstrates that Ellen has made a valid connection to her mental model of problem-solving and that she recognises that the skills she is developing will have authentic applications later in her adult life.

Second, Bree is making her own individual, idiosyncratic link of problem-solving skills to the social construction concerns she was experiencing at school. This, too, is a valid application of the strategies she is developing because she had been running her mental models of problem-solving in social constructivist contexts with some obvious stultifying effects. When probed further about the use of problem-solving skills, Bree appeared to apply “group-think” (Babbie, 2007, p.309) phenomena because she included comments about payment of wages in the workforce as part of her response (Table 9.5). However, her comments could also be interpreted as an acknowledgment of the legitimacy of Ellen’s comments that held specific reference to wages.

Ellen appeared to recognise the totality of the ideas being presented, including the suggestion given by the interviewer about solving a mathematics problem, when she summarised the uses of problem-solving skills. Table 9.5 shows her concluding comments of problem-solving being used at school, with friends, for maths, and, indeed, “all sorts of things”. The students’ mental models of problem-solving saw the application of strategies, such as reviewing steps, balancing time with different friendship groups, and creating and solving calculations, as being relevant to diverse areas of their lives as learners, as members of social groups, and for use as workers in the future. These mental models, while including some modifications as mentioned above, were consistent with previously exteriorised mental models for problem-solving.

The students’ mental models also matched those that Pamela saw developing within all the students with whom she worked. She believed the application of problem-solving skills was fundamental to developing independence in learning because it enabled the students to gain control of their learning. She proposed that students realise that "they can think for themselves and they can make decisions". This self-actualisation enabled them to solve the problems they encountered and "changes their way of looking at what learning actually is". Pamela believed that by enabling the students to participate in such an open-ended learning environment that fostered active problem-solving and, having worked their way through the disequilibrium that comes with this change in thinking, they developed an understanding that they could, indeed, have control over their personal learning journey. They no longer viewed her, the teacher, as "having all the answers" and that a huge shift in their confidence as independent learners came about through the realisation that all of them were on a "journey together".

Pamela's mental model of social constructivism did not match Bree's mental model. Pamela believed giving students the opportunity to "verbalise what's going on in their head" encouraged them to talk more with peers while in partnerships in class activities. An outcome of this was "team synergy" that occurred where "their ideas evolve because they can bounce off each other" that then enables them to develop greater confidence (Pamela, Longitudinal Interview 30 October 2006). This did not occur for Bree and her mental models of working in class groups have not promoted greater confidence or a positive synergistic effect, even in Year Seven.

The reconstruction process of generating robust mental models through quality dialogue between partners (Barker, van Schaik, Hudson, et al., 1997) highlights the importance of learning activities that foster social construction and open-ended, problem-solving activities. The process also needs to promote useful negotiation strategies that learners can adopt to enable them to collaborate productively with others. Rich and non-debilitating powerful mental models, that are stored effectively for retrieval and modification, are more likely to develop, consciously and unconsciously (Barker, van Schaik, Hudson, et al., 1998), through successful social learning interactions.

Assessment

In November 2005, the student participants had engaged in an assessment activity where they were required to design and complete an assessment task set by a fellow research participant. Subsequently, they were interviewed in a Focus Group interview about their mental models of assessment, from the point of view of the assessor and the person being assessed (Chapter 7). When the students were interviewed, as part of the longitudinal aspects of the study in March 2006, one aim was to establish if the mental models they exteriorised during the group interview in November 2005 had remained stable.

In March 2006, both Bree and Ellen exteriorised their mental models of assessment. These confirmed that assessment was relevant if it was conducted at the time they were learning and with sufficient time to complete the tests or assessment tasks (Chapter 8). Their preferred assessment options included the opportunity for students to show or demonstrate what they could achieve, thus confirming the constancy of their mental models from November 2005 (Chapter 7). Modifications, in March 2006, added the choice to work alone or in a group when being assessed.

When questioned in October 2006, as to generic assessment issues, the students' comments, shown in Table 9.6, focus on the assessment of everyday, general tasks.

Table 9.6: Students' mental models of assessment issues.

Ellen	Just do your general work. It shows your improvement. In a test you're always worrying and you're not really concentrating on what you're doing. But in general work, you're always trying to concentrate because you know [pause]
Bree	It's an everyday task.
Interviewer	So, are everyday tasks a better indicator of what you can do and learn than a test?
Bree	Yes.
Interviewer	Which one's better? If I gave you a choice, do you want to show your everyday tasks or do you want to do a test?
Bree	Everyday tasks.
Ellen	Everyday tasks because [pause] learning [pause] you're showing how much you have learned.
Bree	Every day tasks. Yes, because as Ellen said, we don't have to worry about what we're doing in everyday tasks because you do it every day. And with tests, they're [pause] they come around once or twice a year, and if you did everyday tasks, they would happen every day and you would get used to it.

Assessment, preferably, involves the completion of “everyday tasks” in general classroom activity; a mental model exteriorised by both. General classroom activity involves constant application of skills described by Ellen as showing your “improvement”. Tests, for both students, elicit emotions of stress and worry that do not contribute to an effective learning environment.

Tests may have detrimental effects on students’ capacity to learn and to demonstrate what they have learned due to increased anxiety of assessment and the limitation of most testing instruments to provide information on complex cognitive processes. Bree and Ellen had been involved in state-wide Year Seven standardised tests in August 2006. These systemic tests are held annually with Year Seven students and include tests on literacy and numeracy. There is increasing political pressure on teachers, by the Australian Federal Government and the state bureaucracies, to validate their pedagogical practice of addressing key elements of the curriculum, judged by how well their students perform in these tests (Freebody, 2005). While a discussion of the advantages and disadvantages of such political interference in the assessment of students in such a mandated way is beyond the scope of this study, the anxiety felt by the students when undertaking such a rigorous testing regime does have a significant impact on their mental models of learning and assessment.

The students, Bree and Ellen, described how they spent many days in preparation for the tests to ensure that they were familiar with the style of questioning. This act of “teaching for a test” is clearly communicated to the students, who adopt the anxiety felt by the teachers in their quest to have students prepared for the event. As Bree suggested, if a student was assessed on everyday tasks in regular classroom activities, then they would be accustomed to demonstrating their capabilities. This acknowledgment indicates her mental model of assessment involves a much more equitable assessment regime than the one to which she had been exposed in 2006.

Assessment can provide formative information to the learner about their capabilities within a domain. Bree and Ellen were asked how doing an assessment task, such as a test, helps them as learners. They responded with clarity, as shown in the following section of transcript (Table 9.7).

Table 9.7: Students' mental models as to how assessment can help learning.

Interviewer	Does doing an assessment piece help you learn?
Ellen	No! Not really, because doing an assessment piece is like going over it so the teacher knows what you've learnt. You don't really learn. You're going over it.
Bree	When you're doing assessment you're just writing down what you've already written down.
Interviewer	Okay?
Bree	It could be a waste of time — almost all the time — because it's, like, you've already done it in class and the teachers are making you re-do it.
Interviewer	Yes?
Bree	And wouldn't it be easier if the teacher just walked around and watched you do it?
Interviewer	Any thoughts on that?
Ellen	Yeah, that would be better. Through your general work, you don't have the nerves and you don't try harder when you're learning it and [when or if] you get really good marks, it shows the teacher what you've learned. Just through that little space of time.
Interviewer	So when do you perform at your best?
Bree	Personally, when I don't think anybody's looking or watching.
Interviewer	Why is that?
Bree	Because, say, when people are watching, it's like you've got to put on a show, so you're trying to get it right. And when you try so hard, you'll forget most of the time what [are], actually, the right answers.
Interviewer	What about you Ellen? When do you perform at your best?
Ellen	Probably through general work because I find it easier. Somehow [I] find it easier. [Pause] Because even [pause] you know, that PM reading thing [standardised reading test] that you have to do? It's really nerve racking.

The students retrieved mental models of assessment that indicated some variation to those exteriorised in other data collection episodes (Chapters 7 & 8) such as their preferences: Bree: written assessment, writing in journals, and showing how to build a robot , and Ellen: creating a PowerPoint™ show with pictures and words, and showing how to build a robot. While neither had included specific references to showing capability in classroom activities in previous data collection episodes, Ellen had commented in November 2005 that having “someone watching you” was disconcerting and detrimental to assessment performance (Chapter 7). Putting on a “show” for assessment purposes was now seen as stressful and not the most efficacious way to measure capabilities.

Bree and Ellen preferred the opportunity to demonstrate what they could achieve to enable them to verify their understanding without a specific testing or assessment strategy being implemented. When consideration is given to the complexity of content and process at primary school level, their observations are reasonably valid. The close working relationships established in a primary classroom necessitate a teacher’s familiarity with the ability of each student, particularly if instruction is individualised at each student’s level of understanding.

Some tests are literally “a waste of time”, as Bree proposed. She questioned the validity of re-performing a task, that has already been successfully demonstrated in general work, for a test. She proposed that a teacher could just as easily observe a student performing the task in general class work rather than to create a test so as to witness the re-performance of the same task (Table 9.7). Bree has cast refreshing eyes on standard assessment practice and arrived at a logical conclusion of it being time wasting.

Discourse is a valid assessment strategy (Chervin & Kyle, 1993; McNeil, 2007; Wilks, 2005). Pamela conducted interviews with the students about their progress through the robotics activities as part of her assessment plan in 2005. Assessment involving a student talking about their work was also discussed during the Focus Group interview held in November 2005. The students were now questioned again in October 2006 about their experiences of having discourse as part of their assessment. Bree believed it “would be a lot easier than writing it down because you’re talking about it and discussing it” while Ellen suggested writing it down first, “and then you could talk about it and show how you figured it out”. She also saw this as an opportunity to get some help to “fix” any problems you might be having with the work. These clearly-expressed mental models of assessment, through discourse, matched Pamela's mental model and indicated that the experiences the students had had, during the robotics activities, had contributed to the development of mental models of assessment that included a variety of methodologies that were useful for the learners and insightful for the teachers.

Portfolios are also a key element of authentic assessment strategies (Herron & Wright, 2006; Kimbell, 2002; Royer et al., 1993). While Pamela's mental model of assessment had remained stable throughout the twenty months of the study, she modified it in 2006 to include portfolios. This addition, suggested by other teachers working with robotics in the school district, enabled the students in the second cohort to track their individual progress through the activities. The portfolio included key times for conversations about the record of achievements they had logged. Assessment was not, however, the end product but became "a tool that just advises them where to go from there." In addition, Pamela also observed students during the robotics activities. This matched the mental model of assessment that Bree and Ellen had proposed during their interview: regular class work and the opportunity to be involved in discourse about what had been learned.

Pamela supported the inclusion of a reflective process during, and at the end of, each learning experience that included the opportunity for students to verbalise what they had learned. She believed that "real learning happens when they start talking about it because it consolidates it for them". A conversation that is fluent enables the students to realise that they have learned. It also highlights any gaps in their knowledge thereby creating the opportunity for extra support to be provided to overcome any deficiencies. Pamela's mental models of teaching, learning, and assessment remained holistic and recognised, at a fundamental level, that all children are "capable". Confidence is what matters.

In Summary

Here, we come to the end of the longitudinal case study of these three participants. The contribution this part of the study has made to the understanding of mental models in teaching, learning, and assessment is critical. Data clearly demonstrated that, while some effective mental models remain stable over time due to their ability to guide successful practice, some mental models adapt to accommodate new experiences from the environment and the individual's interactions with phenomena within that environment. Some mental models enable the participant to manage their interactions, while some mental models manage the participants as they negotiated the learning journey.

Bilbo and Gollum shared riddles, one of which addressed *time* and its association to the mental models of the inhabitants of Middle Earth.

> This thing all things devours:
> Birds, beasts, trees, flowers;
> Gnaws iron, bites steel;
> Grinds hard stones to meal;
> Slays king, ruins town,
> And beats high mountain down (Tolkien, 1937, p. 74).

As we head for home, there will be some pertinent observations about the significant role mental models have in all classrooms as this is the time and place to consolidate the significance of this study and its contributions to the education community. The study had been conducted over a long period of time and it is this longitudinal aspect that enables valid contribution to be ascertained.

CHAPTER TEN: *Conclusion*

"'There is a long road yet,' said Gandalf.
'But it is the last road,' said Bilbo." (Tolkien, 1937, p. 274)

Introduction

This study has established that as each learner moves along their learning pathway they will create, retrieve, and modify mental models to meet their individual cognitive needs. The measurement of the distance that they will travel in a predetermined time is of interest to several parties, including the students themselves, their parents, teachers, and the researchers who seek to gain an understanding of the passage that learners take. This chapter contributes to this evolving picture of teaching, learning, and assessment and will open with what this particular study offers.

Contribution to Research

This study did not research constructionism (Papert, 1991), that is the "usual" methodology with respect to robotics (Chapter 3). It focuses on constructivism (Derry, 1996; Duffy & Jonassen, 1992; Moshman, 1982; Piaget, 1970; von Glaserfeld, 1995) and social constructivism (Anderson et al., 1997; Brown, 1993; Smagorinsky, 2001; Smagorinksy & O'Donnell-Allen, 2000; Vygotsky, 1978) research using robotics as a tool to centre its lens on the mental models of teaching, learning, and assessment. It has demonstrated that one research project can impact the research community in a variety of ways as listed below. This project:

1. addressed a significant gap evident in the research of the mental models of middle years students;
2. included a longitudinal study of Year Six students' and their teacher's mental models;
3. used an adapted data collection method (Stimulated Recall) to study mental models;
4. used new data collection methods (Teach-Back and Focus Groups) to study the mental models;
5. included a 20 month longitudinal study of teaching, learning, and assessment;

6. used the researcher's individual journey as a repository of momentous decision-making moments to underscore the process of modification that occurs when reality bites into the research organism; and,
7. included a rich variety of data collection methods in one study, including:
    a. participant journals (weekly and at notable times);
    b. pre- and post-experience Likert Scale Questionnaires;
    c. pre- and post-experience semi-structured interviews (individual and group);
    d. a focus group interview based on an assessment episode;
    e. two rounds of stimulated recall interviews; and,
    f. a teach-back episode (Chapter 3).

While already addressed in previous chapters, these contributions are revisited to highlight the significance of their contribution.

Research Focus

Many studies have been conducted into the mental models held by undergraduate students at university (Arentze, Dellaert & Timmermans, 2008; Goodwin & Johnson-Laird, 2008; Merrill & Gilbert, 2008; Nguyen & Henderson 2008; Pausawasdi, 2002; Williamson, 1999) but few have delved into those held by middle years students (Henderson & Tallman, 2006; Stripling, 1995; Schmakel, 2008) and those studying robotics (Barchi et al., 2002; Eronen et al., 2002; Miglino et al., 1999). This longitudinal study focused its methodological lens on the mental models held by students in the middle years and their teacher as they progress through a discovery-based learning environment that challenged them to develop robust problem-solving skills in a social constructive environment. The teacher's mental model matches and mismatches with her students was a fundamental aspect of the study.

The longitudinal aspect of the study was crucial to investigations into the stability or otherwise of the mental models that had been identified and analysed. The in-depth nature of the study enabled a powerful lens to be focussed on specific mental models, validating the methodology used to gain such data and exposing the impact those mental models have on the teaching, learning, and assessment journey of the participants. While capturing a "moment-in-time" glimpse of the mental models held by participants may be of some value to determine how a particular phenomena is viewed, the modifications or stultification of mental models that occurs over time is what can truly inform researchers of what is taking place and how teaching, learning, and assessment are being negotiated. The data from this study informs the veracity of pedagogical strategies over time because it gathered such information.

Research Methodology

Multiple "stories" were mapped through the variety of instruments that substantiated the data through method triangulation (Burns, 2000; Miles & Huberman, 1994). Maintaining an in-depth and rigorous study was a priority and the goal was to maximise the reliability of the data being gathered.

A significant contribution of this study was the instantiation of a relatively unused data collection method and the inauguration of a new one. A wide literature search has not located reports of the employment of the particular configuration of the new data collection method launched in this study. The adapted data collection method used the stimulated recall methodological lens. While powerful, its standard application, in this study, failed to uncover the data necessary for a thorough mental model investigation. The detail of the adaptation was addressed (Chapters 3 & 5). A question added to the protocol resulted in noteworthy improvement in both the quantity and quality of useable responses and signifies that such introspective probes can be used successfully with young participants. The additional question, "What were you doing?" added prior to the standard probes, proves that this form of questioning, tucked away in Marland et al.'s (1992) appendices, is a valuable step in the protocol.

This study introduced of a new research method that combined two experiences for the participants to create a novel investigative probe. While a focus group interview is not a new data collection method, when linked explicitly with a student-designed assessment task (Chapters 3 & 7) it created a unique data collection instrument for the identification of individual and distributed mental models. The assessment tasks, held prior to the group interview, required the students to adopt the role of an assessor and then the role of the one being assessed through designing one task and completing another task, respectively (Chapter 7). All participants shared a unique experience that heuristically challenged them cognitively and socially.

The focus group interview directed their attention “systematically and simultaneously” (Babbie, 2007, p. 308) on these shared experiences. The four students were interviewed in a milieu that not only replicated the situated-cognitive environment of the classroom but also introduced an authentic setting for the exteriorisation of distributed mental models. While group interviewing is not a new method for discerning the thoughts of young participants (e.g., Lewis, 1992), the study’s interview foci on both a choreographed shared experience of learning and assessment and an ongoing learning adventure, is novel.

Limitations of the Research

Limitations of time and personnel meant that participant numbers had to be limited and raised two significant prospects for potential projects: increased number of participants and a gender focus.

First, the small numbers of participants mean that the findings, while of significance, cannot be generalised to the greater population (Babbie, 2007; Burns, 2000). Larger numbers of participants could have been involved if (a) the method of investigation had only included quantitative methods, for example, utilising Likert Scale attitudinal questionnaires or if (b) a greater number of qualitative researchers were available in the field to conduct the number and variety of interviews used in this study. However, the intimacy of this investigation did offer the opportunity to “focus on the complexities and qualities in educational action and interaction that might be unattainable through the use of more standardised measures” (Burns, 2000, p. 390) and is, therefore, a strength of this research.

Second, the project was confined to general areas of teaching, learning, and assessment from a homogenous point of view of individual as “teacher” or “learner”, rather than any specific focus on gender. Such a focus, within this rich problem-solving domain under the umbrella of a mental model study, would shed significant light on matters pertaining to engagement in learning at the middle years level of schooling. Students in this sector have a propensity to disengage with learning as they enter high school (Carrington, 2002; Kenway, 2000). Therefore, a study of mental models with a focus on gender issues would significantly illuminate pertinent issues, particularly in strongly gendered subjects such as design and technology.

Implications of Research

The results from probes at each significant point along the journey have been discussed in some detail already. Therefore, this section provides a summary and implications for classroom practice from this unique investigation of mental models.

Pedagogical Implications: Teaching, Learning, and Assessment

The implications for teaching, learning, and assessment include:

1. planning for the timeliness of intervention to promote functional mental models of learning;
2. evaluating the intensity of intervention required to change habituated, ineffective mental models of learning in problem-solving;
3. teaching specific strategies for successful collaborative negotiation in groups to strengthen mental models of social construction;
4. appraising externalised mental models through cognitive, particularly metacognitive, activity to provide a basis for deeper conceptual understanding of the requirements of the learning task and improved problem-solving capability;
5. developing robust mental models that have effective communication functionality that contribute to unambiguous and authentic assessment strategies; and,
6. compiling multiple ways of communicating what is known in a domain experienced by teachers and students thereby creating diverse and individually meaningful assessment practices that provide useful information about teaching and learning success.

Timeliness of intervention.

One of the pedagogical issues that teachers consider regularly is the timing of intervention strategies. In this study, Sam's ineffective mental model of journal coding precluded him from communicating clearly with this partner, Jim, or his teacher, Pamela, about his progress through the robotics program (Chapter 5). His ineffective mental model had no impact, per se, on his ability to negotiate the robotics learning environment. Sam had not attributed relevance to the coding requirement until challenged to do so — accomplishment rather than the annotation of, and reflections on, his progress were Sam's priority (Chapter 5).

Nevertheless, Pamela's timing of intervention, while distracting Sam at the time, was purposeful. The timing of intervention is crucial and requires students having both the mental models to accommodate the conceptual, declarative, and procedural knowledge embedded in the intervention and a readiness, evident in their understanding of their gap in such knowledge, to be receptive to that accommodation. Students need a level of expertise in their mental models of the learning situation (Eylon & Linn, 1988) and the relationships and predictions they construct, in order to make individual progress.

Intensity of intervention.

Determining the intensity of intervention required to change habituated learning patterns can be challenging for teachers. Seel and Strittmatter (1989) stated that learners can find it difficult to abandon or alter a redundant mental model unless they are taught a more useful mental model that is influential and consistent with what is known. The intervention necessary to secure changes in ineffective mental models requires teachers to scaffold learning (Puntambekar & Hubscher, 2005) in a way that supports learners through such confronting episodes.

This study provided evidence that Jayne was operating with stultifying problem-solving mental models: they limited her ability to resolve construction problems in the robotics activities (Chapters 5 & 7). Jayne's systematic retracing of steps failed to engage her in complex consideration of those steps with the profundity required to remediate errors. Jayne believed that by doing "it" over and over and again should result in automatic correction (Chapter 5).

Teachers cannot make assumptions about learners' ability to problem-solve independently. Creating opportunities for discussions with all students with close scrutiny to discourse will uncover what they know, because we cannot talk lucidly about something for which we have no understanding (Pamela, Post-experience Interview, 6 September 2005). Mental models, through their autonomy and fluidity and, as seen in this study, their propensity to continue unchallenged, can be visible enough to inform the teacher when, and with what intensity, to intervene with remediation to correct the deficiency. Mental models, themselves, provide the means to interpret the problem, predict the possible success from the deployment of a variety of solutions, and control performance when instantiating the decided actions.

Intervention for social constructive collaboration.

There are clear implications for teachers who organise group work that involves the distribution of transitory mental models (Anderson et al., 1996) between students. While all of this study's student participants experienced some difficulty with constructing and programming the robots at different times in the study, it was Bree who experienced continued difficulties with engaging in socially constructed learning environments (Chapters 7, 8 & 9). Her ineffective mental model of social construction had remained constant from November 2005 into the following year, to October 2006, when she expressed the problems and their associated reasons; her inability to negotiate resource allocation and contribution of effort from her partners. Bree's ineffective mental models of collaboration were limiting her learning in classrooms (2005 & 2006) where group work was a norm.

Seel and Strittmatter (1989) argued that positive experiences are fundamental for learners to alter their mental models. This study proposes that overt strategies for negotiating social situations for learners be included in teachers' curriculum plans. Repeated opportunities for success in the application of those strategies are advised because one-off experiences are insufficient to modify a long-held and/or stultifying mental model. To promote the problem-solving efficacy of partnership, semiotic mediation strategies using psychological tools, such as language, mathematics, and diagrams (John-Steiner & Meehan, 2000; Smagorinsky, 1995) could also be taught overtly by the teacher.

Appraising mental models for problem-solving.

The conscious appraisal of externalised mental models by a teacher and students, through cognitive and metacognitive activity (Rogers et al., 1992), provides the basis for deeper conceptual understanding of the requirements of the learning task and, therefore, greater problem-solving capabilities. Appraising, or establishing the value, quality, or performance (Moore, 2004) of actions or processes involves: being aware of what one knows and/or does not know; using a variety of learning strategies that meet the demands and nature of the task being undertaken; predicting the success of those strategies; monitoring the success of the effort; and planning ahead to use time in an efficient manner (Glaser et al., 1985). These actions contribute to greater metacognitive awareness for all participants and become a shared and powerful teaching, learning, and assessment tool.

Therefore, metacognitive processes to create, retrieve, and manipulate more effective mental models of learning involves proactive behaviour. This behaviour is created from the willingness to act with knowledge in order to enhance the efficiency of problem-solving spaces. Such control of one's mental models is particularly imperative when the task is new, complex, or contains the possibility of failure in some way (Henderson & Tallman, 2006). Mental models are seen to be the mechanism by which metacognitive skills can be developed (Haycock & Fowler, 1996), due to the way in which "we acquire knowledge, achieve understanding and generalise problem-solving skills to make them available to different situations" (p. 28), as exemplified in this thesis.

Communicating assessment strategies.

The students in this study did not hold matching mental models of assessment with those of their teacher Pamela (Table 7.11, Chapter 7). Pamela's failure to clearly communicate her mental model of assessment using discourse resulted in the students' failure to incorporate the strategy into their mental models. This was a significant gap in the students' knowledge.

Effective multi-modal communication skills are essential for effective pedagogical practice. As new technologies evolve, students and teachers will require competency in a variety of digital and inter-personal domains so that they clearly and confidently communicate what it is that they know or expect others to know.

The development by teachers and students of robust mental models that have rich multi-modal communication functionality is essential and, more importantly, possible to achieve. This study demonstrated that students can contribute to the development of these assessment strategies, because they are constantly exposed to such multiple methods of communicating in their everyday school and non-school life.

Multiple authors for multiple assessment strategies.

Expressing what we know about a domain of learning is a complex process that often involves multiple ways of communicating. Just as learners are taught the art of story-telling (through narrative writing, graphic arts, and drama), the art of communicating what we hold in our mental models can also be taught. Mental models serve a communication function by allowing what we know to be known to others.

The communication function of mental models means they play an integral role in the how learners and a teacher progress through problem solving-situations (Barker, van Schaik, Hudson, et al., 1998) and negotiate assessment instruments. When we communicate or share what we know with others, we can be involved in discourse where analogous shared examples are used to explain our understanding (Newton, 1996; Halford, 1993; Johnson-Laird, 1983); we might create a concept map (Williamson, 1999), or we might be involved in the active construction of a shared, transitory (Anderson et al., 1996) mental model as we work with others.

Communication and collaboration is important. If teaching and learning is a shared journey, assessment, too, can be a joint venture. The students in this study offered well-articulated and conceptualised ideas about assessment (Chapter 7, 8 & 9) that could be used to conduct valid, reliable, creative, and authentic assessment strategies. Communication and joint authorship of assessment strategies will contribute to the creation, retrieval, and modification of mental models for authentic assessment.

Proactive Strategies for Improved Learning and Problem-Solving

Mental models are recursive (Power & Wykes, 1996) and call upon themselves “during processing, providing both computational power and a mechanism by which the self, and the self-reflective aspects of the self, can be understood” (p. 205). Being aware of how mental models are run can inform metacognitive awareness that, in a cyclical process, will aid the creation and use of future mental models. The processing of mental models, that enable inferential thinking and prediction of problem solutions, can be understood better by the way students develop metacognitive skills. Selecting strategies, predicting success, and monitoring outcomes involves the functions of mental models: explaining, predicting, controlling, diagnosing, and communicating.

All students can develop skills that promote their metacognition (Schoenfeld, 1987) that will improve their opportunities for success. Understanding ourselves and the strategies we use to solve problems are included in our mental models (Power & Wykes, 1996). Jayne, the student participant who could not understand what went wrong to produce the incorrect movement of the robot during the teach-back episode with Mary (Chapter 7), was not using metacognition to assess of her own understanding (Power & Wykes, 1996). There must be a willingness to “reformulate or restructure the model, articulate it, and translate the outcome” (Newton, 1996, p. 206) if the mental model being created is to be an adequate mental representation of the situation or problem. Mental models should be generative (Newton, 1996) thereby contributing to future understandings.

The powerful predictive function of mental models (Chapter 2) is perhaps the major determiner as to how a teacher can promote the accuracy and usefulness of mental models. Teachers can engage learners in activities that will retrieve the appropriate mental models from long-term memory, or create and store new ones, and use them to predict how they will solve a problem within a domain (Norman, 1983; Johnson-Laird, 1983). In this study, students used the weekly journal to make predictions about their future success in the robotics activities and to record what activities they would attempt in a subsequent lesson based on the success they had experienced in the preceding lesson.

The predictive function of mental models was also evident in the strategies the participating students were using when they applied problem-solving procedures to move through the construction and programming activities in robotics. In the second stimulated recall episode in July 2005 (Chapter 5), Pamela guided Sam through articulating problem-solving strategies. This use of forced prediction enabled Sam to retrieve, run, and modify his mental models of problem-solving in order to create a more functional mental model of robotics. As a consequence he incorporated useful problem-solving strategies into his mental model of robotics, evidenced by responses in the longitudinal interview in March 2006 when he revealed that he used those very strategies when confronted with a problem. The functionality of Sam’s mental models of problem-solving had been developed through the use of forced prediction.

Forced prediction (Newton, 1996) encourages learners to articulate a problem and use the explaining and communicating functions of mental models in an active process. If having a mental model for something means that we have some understanding of it (Johnson-Laird, 1983), then a teacher’s priority is to ensure that learners are actively engaged in developing predictive functional mental models so they understand and learn.

In Closing

Teachers use diverse pedagogical practices based on educational and psychological research that aims to enact efficient and effective teaching, learning, and assessment. They recognise that different students learn at different rates and that students approach problem-solving situations, such as those in robotics, in different ways. di Sessa (1988) studied this individuality and proposed that learners store information in pieces; they have different mental models for different purposes. A competent teacher will acknowledge the many links that students need to use to embed a new or modified mental model into long-term memory. di Sessa (1988), Randell (1993), and Stenning (1992) suggested that each mental model an individual creates would need to have such a linking mechanism for manipulation in working memory. Of course, once the mental model, or part of a mental model, has been successfully run and adapted in working memory, it would be encoded to long-term memory.

One of Norman's (1983) characteristics of mental models is instability due to both their evolutionary nature and the "humanness" of individuals who, over time, forget or mix up details. If mental models are not run frequently, their power to be functional diminishes and a person's ability to run them would be limited (Norman, 1983; Power & Wykes, 1996). However, well-linked and frequently run models should be more robust and offer the individual more computational power. Mental models that are incomplete, inaccurate, or stagnant require re-evaluation and modification. Mental models may also have idiosyncratic quirks (Norman, 1983) but, if they are perceived as functional, they will be retained by the individual. This research has substantiated these mental model features and has studied key characteristics, such as runnability, functionality, and idiosyncrasy, through its intimate, longitudinal lens.

Mental models are multi-dimensional and multi-functional but become less complex when described in the simple terms of how we express what we know (Jonassen, 1995). If we believe that each learner is an individual and that their ways of interacting with, and on, the world reflects that individuality, then using mental model theory as practice in classrooms is fundamental. Each learner can develop a functional way of communicating what they know, understanding and controlling how they learn, and predicting how far they can travel on their learning journey.

Each teacher joins them on that journey and becomes a guide who engages their interest, challenges their expectations, and celebrates their success.

And so the story goes…

And Bilbo came to the end of *his* journey; he came to a rise in the road and looked upon his very own home in the distance and spoke to his companions:

Road go ever ever on,
Over rock and under tree,
By caves where never sun has shone,
By streams that never find the sea;
Over snow by winter sown,
And through the merry flowers of June,
Over grass and over stone,
And under mountains in the moon.

Roads go ever ever on
Under cloud and under star,
Yet feet that wandering have gone
Turn as last to home afar.
Eyes that fire and sword have seen
And horror in the halls of stone
Look at last on meadows green
And trees and hills they long have known.
(Tolkien, 1936, p. 276)

The students, teacher, and researcher in this study, also come to the end of their journey through the explorations of mental models. However, their teaching, learning, and assessment goes ‘ever on’.

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APPENDIX A

Ethics approval was granted for the research. Ethics Number H1974.

JAMES COOK UNIVERSITY
TOWNSVILLE Queensland 4811 Australia Telephone: (07) 4781 4111

Consent Form A

Principal Investigator	Ms Christine Edwards-Leis
Project Title	Mental Models and Robotics in Middle Schooling
School	Education
Contact Details	Christine.edwards-leis@jcu.edu.au School Phone: 3284 0899

DETAILS OF CONSENT:

The focus of this research project is the mental models (that is, the views, thoughts, beliefs, and mental strategies) held by students and their teacher before, during, and after a learning experience involving robot construction.

The participation of your child is sought as a learner who constructs a robot as part of learning experiences for their year level. Your child will be asked to reflect on their mental model of robotics before, during, and after the learning experiences.
The students who participate in this research will be asked to be involved in the following for the collection of their views in designing and creating a robot:

- Two whole class written questionnaires in March and in June (approx 15 minutes);
- Four "selected" participants (see letter for details on selection):
  - 20 minute interview at the beginning of March before the robotic learning experiences;
  - videotaped robotics lesson with a 20 minute interview occurring the following day;
  - 20 minute interview at the end of June after their robotic learning experiences;
    - 20 minute interviews in 2005 and 2006 to determine longitudinal changes in their mental models of robotics;
  - 15-20 minute teach-back episode at the end of June where students will teach another student how to construct a robot;
  - I will also be using the following to help me understand the students' thoughts, ideas, and beliefs about their robotics activity:
    - The students' journals (all students are required to do this as part of their classroom activities)
    - Teacher observations of the students when designing, constructing, and programming their robots. (It is the teacher's practice to observe students during class activities)

The robot constructed by your child will be assessed in accordance with the criteria sheet developed for this unit of work for the students of this year level.

The outcome of this research will be presented as part of a doctoral research in a written form and copies of published work will be made available to you.

JAMES COOK UNIVERSITY
TOWNSVILLE Queensland 4811 Australia Telephone: (07) 4781 4111

CONSENT

The aims of this study have been clearly explained to me and I understand what is wanted of me. I know that taking part in this study is voluntary and I am aware that I can stop taking part in it at any time and may refuse to answer any questions.
I understand that any information I give will be kept strictly confidential and that no names will be used to identify me with this study without my approval.

Name of Student: ________________________Parent/Guardian: ___________________

Signature (Parent/Guardian): ____________________Date: _______________________

Please complete each item:

1. I give / do not give my consent for my child to participate in the research project by completing the two 15 minute written questionnaires.
2. I give / do not give my consent for my child to participate in the interviews (approximately 20 minutes each)
3. I give / do not give my consent for my child to be part of the videotaped classroom lesson (approximately 45 minutes)
4. I give / do not give my consent for segments of the audiotape, videotape, and photographs to be used for conference presentation purposes by the researcher. (The students will NOT be identified by name.)

Name of Parent / Guardian :__________________________(please print)

Signature *(Parent/Guardian)*:___________________________ Date: ________________

Witnessed by Researcher obtaining consent

Name: Christine Edwards-Leis

Signature: _____________________________ Date: ____________________________

APPENDIX B

Ethics approval was granted for the research. Ethics Number H1974.

JAMES COOK UNIVERSITY
TOWNSVILLE Queensland 4811 Australia Telephone: (07) 4781 4111

Consent Form B

Principal Investigator	Ms Christine Edwards-Leis
Project Title	Mental Models and Robotics in Middle Schooling
School	Education
Contact Details	Christine.edwards-leis@jcu.edu.au School Phone: 3284 0899

DETAILS OF CONSENT:

The focus of this research project is the mental models (that is, the views, thoughts, beliefs, and mental strategies) held by students and their teacher before, during, and after a learning experience involving robot construction. The participation of your child is sought as a learner who will be taught to construct a robot. Your child will be asked to participate in one teaching/learning episode with one other student who has undertaken robotics in semester one.

The outcome of this research will be presented as part of a doctoral research in a written form and copies of published work will be made available to you.

CONSENT
The aims of this study have been clearly explained to me and I understand what is wanted of me. I know that taking part in this study is voluntary and I am aware that I can stop taking part in it at any time and may refuse to answer any questions. I understand that any information I give will be kept strictly confidential and that no names will be used to identify me with this study without my approval.

Name of Student: ___________________________Parent/Guardian: _____________________

Signature (Parent/Guardian): ______________________Date: _________________________

Please complete each item:

1. I give / do not give my consent for my child to participate in the research project by completing the 15-20 minute teaching/learning episode.
2. I give / do not give my consent for segments of the audiotape to be used for conference presentation purposes by the researcher. (The students will NOT be identified by name.)

Name of Parent / Guardian :____(please print)

Signature *(Parent/Guardian)*:__________________________ Date: __________________

Witnessed by Researcher obtaining consent

Name: Christine Edwards-Leis

Signature: _______________________________ Date: ________________________________

APPENDIX C

Ethics approval was granted for the research. Ethics Number H1974.

JAMES COOK UNIVERSITY
TOWNSVILLE Queensland 4811 Australia Telephone: (07) 4781 4111

Consent Form C

Principal Investigator	Ms Christine Edwards-Leis
Project Title	Mental Models and Robotics in Middle Schooling
School	Education
Contact Details	Christine.edwards-leis@jcu.edu.au School Phone: 3284 0899

DETAILS OF CONSENT:

The focus of this research project is the mental models (that is, the views, thoughts, beliefs, and mental strategies) held by students and their teacher before, during, and after a learning experience involving robot construction.

Your participation is sought as a teacher who guides students to construct a robot as part of learning experiences for their year level. You will be asked to reflect on your mental model of teaching and learning with robotics before, during, and after the learning experiences.

You will be asked to be involved in all aspects of the research for the collection of your views in teaching and learning with robotics including:

- Two written questionnaires in March and in June (approx 15 minutes);
- 30 minute interview at the beginning of March before the robotic learning experiences;
- videotaped robotics lesson with a 45 minute interview occurring the following day;
- 30 minute interview at the end of June after the robotic learning experiences;
- three 20 minute interviews for longitudinal aspects of the research to be held in 2005, 2006, and early 2007; and
- I will also be using the following to help me understand your thoughts, ideas, and beliefs about your views on teaching and learning with robotics:
    - Teacher observation journal of the students when designing, constructing, and programming their robots;
    - Teacher assessment of mid-experience and end working papers and robot construction according to criteria established with reference to the Technology syllabus; and
    - Curriculum documentation relevant to the research.

The outcome of this research will be presented as part of a doctoral research in a written form and copies of published work will be made available to you

JAMES COOK UNIVERSITY
TOWNSVILLE Queensland 4811 Australia Telephone: (07) 4781 4111

CONSENT

The aims of this Study have been clearly explained to me and I understand what is wanted of me. I know that taking part in this study is voluntary and I am aware that I can stop taking part in it at any time and may refuse to answer any questions. I understand that any information I give will be kept strictly confidential and that no names will be used to identify me with this study without my approval.

Name of Participant :____

Signature :____ Date: _______________

Please complete each item:

1. I give / do not give my consent for my participation in the research project by completing the two 15 minute written questionnaires.

2. I give / do not give my consent for my participation in the three interviews (approximately 30 and 45 minutes each)

3. I give / do not give my consent for my participation in the three longitudinal interviews (approximately 20 minutes)

4. I give / do not give my consent to be part of the videotaped classroom lesson (approximately 45 minutes)

5. I give / do not give my consent for my curriculum documentation and teacher observation journal and curriculum documents to be used.

6. I give / do not give my consent for segments of the audiotape, videotape, and photographs to be used for conference presentation purposes by the researcher. (The teacher will NOT be identified by name.)

Name of Participant :____(please print)

Signature :____ Date: ______________

Witnessed by Researcher obtaining consent

Name: Christine Edwards-Leis

Signature: _______________________________ Date: ________________________________

APPENDIX D

Ethics approval was granted for the research. Ethics Number H1974.

JAMES COOK UNIVERSITY
TOWNSVILLE Queensland 4811 Australia Telephone: (07) 4781 4111

Consent Form D

Principal Investigator	Ms Christine Edwards-Leis
Project Title	Mental Models and Robotics in Middle Schooling
School	Education
Contact Details	Christine.edwards-leis@jcu.edu.au
	School Phone: 3284 0899

DETAILS OF CONSENT:

The focus of this research project is the mental models (that is, the views, thoughts, beliefs, and mental strategies) held by students and their teacher before, during, and after a learning experience involving robot construction. Your participation is sought as a parent of a learner who will be taught to construct a robot. You will be asked to participate in one questionnaire to provide a broad community view of the response to this innovation within the school. The outcome of this research will be presented as part of a doctoral research in a written form and copies of published work will be made available to you.

CONSENT
The aims of this study have been clearly explained to me and I understand what is wanted of me. I know that taking part in this study is voluntary and I am aware that I can stop taking part in it at any time and may refuse to answer any questions. I understand that any information I give will be kept strictly confidential and that no names will be used to identify me with this study without my approval.

Name of Participant :____

Signature :____ Date: _______________

Please complete each item:

1. I give / do not give my consent for my participation in the research project by completing the 15-20 minute questionnaire.

Name of Participant :____(please print)

Signature:_____________________________________ Date: __________________

Witnessed by Researcher obtaining consent

Name: Christine Edwards-Leis

Signature: _____________________________ Date:___________________________________

APPENDIX E

Pre-Experience Likert Scale Questionnaire: Student

I am interested in your feelings about the following statements. Read each statement carefully and decide how you feel about it. Please respond to each item as honestly as you can.

Name:………………………… Pseudonym………………….. Date……………

You need to circle a number to show how you feel.
The numbers in the right hand columns mean the following:

1. Strongly agree
2. Agree
3. Undecided or not sure
4. Disagree
5. Strongly disagree

Student Questionnaire

	Statement	Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
1	It is easy to make a robot.	1	2	3	4	5
2	I have the skills required to make a robot.	1	2	3	4	5
3	This is the first robot that I have created.	1	2	3	4	5
4	It is difficult to use the computer program for robotics.	1	2	3	4	5
5	I see myself making more robots.	1	2	3	4	5
6	Robots should be able to do more than one thing.	1	2	3	4	5
7	It is fun creating robots.	1	2	3	4	5
8	My robot will be able to follow the instructions I plan.	1	2	3	4	5
9	It is important to design what your robot will do before you construct it.	1	2	3	4	5
10	I learn more when I can experiment with the robots.	1	2	3	4	5
11	Creating robots is challenging.	1	2	3	4	5
12	I learn more when I work in a group.	1	2	3	4	5
13	The robot I make with my group will be better than the robot I would make alone.	1	2	3	4	5
14	The way that I look at robots will change.	1	2	3	4	5
15	I want to choose the actions my robot will do.	1	2	3	4	5
16	I become worried when I make mistakes.	1	2	3	4	5
17	Robots should move and act like humans in order to be useful.	1	2	3	4	5
18	It doesn’t matter what a robot looks like, as long as it can complete a task.	1	2	3	4	5

	Statement	Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
19	Robots are more useful if they can talk to you.	1	2	3	4	5
20	I would rather interact with a robot that: looks like a human.	1	2	3	4	5
21	I would rather interact with a robot that: has eyes.	1	2	3	4	5
22	I would rather interact with a robot that: has ears.	1	2	3	4	5
23	I would rather interact with a robot that: has a mouth.	1	2	3	4	5
24	Robots have brains that are similar to ours.	1	2	3	4	5
25	The actions my robot does will show me if I have made it correctly.	1	2	3	4	5
26	I do not get upset when I make a mistake.	1	2	3	4	5
27	I find it difficult to remember instructions when I am doing something new.	1	2	3	4	5
28	I am more confident when I have the chance to correct my mistakes.	1	2	3	4	5
29	You learn more when you fix your own mistakes.	1	2	3	4	5
30	I can solve problems by thinking about them and planning what to do.	1	2	3	4	5
31	I like to talk to someone when I am having difficulty in doing my work.	1	2	3	4	5
32	Everyone in my robotics group should have the same goals.	1	2	3	4	5

APPENDIX F

Pre-Experience Likert Scale Questionnaire: Teacher

I am interested in your feelings about the following statements. Read each statement carefully and decide how you feel about it. Please respond to each item as honestly as you can.

Name:………………………… Pseudonym………………….. Date……………

You need to circle a number to show how you feel.
The numbers in the right hand columns mean the following:

1. Strongly agree
2. Agree
3. Undecided or not sure
4. Disagree
5. Strongly disagree

Teacher Questionnaire

	Statement	Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
1	The students will find it is easy to make a robot.	1	2	3	4	5
2	The students have the skills required to make a robot.	1	2	3	4	5
3	This is the first robotics class that I have taken.	1	2	3	4	5
4	It is difficult for the students to use the computer program for robotics.	1	2	3	4	5
5	I see myself taking more robotics classes.	1	2	3	4	5
6	Robots should be able to do many things.	1	2	3	4	5
7	It is fun creating robots.	1	2	3	4	5
8	The robots will be able to follow the instructions the students plan.	1	2	3	4	5
9	It is important for the students to design what their robot will do before they construct it.	1	2	3	4	5
10	Students learn better when they can experiment with robots.	1	2	3	4	5
11	Creating robots is challenging for the students.	1	2	3	4	5
12	Students learn more when they work in a group.	1	2	3	4	5
13	The robot the students make with their group will be better than the robot they would make alone.	1	2	3	4	5
14	Students like to be able to choose the actions their robot will do.	1	2	3	4	5
15	I become worried when I am unsure about how to answer the students' questions.	1	2	3	4	5
16	Students will see robots as being more useful if they respond like humans.	1	2	3	4	5
17	It doesn't matter what a robot looks like, as long as it can complete a task.	1	2	3	4	5
18	Students will see robots as more useful if they can talk like humans.	1	2	3	4	5

	Statement	Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
19	Students would rather interact with a robot that is humanlike in appearance.	1	2	3	4	5
20	Students see robots as having brains that are similar to ours.	1	2	3	4	5
21	The students should be able to problem solve the robot's function by looking at its actions.	1	2	3	4	5
22	Students need lots of scaffolding and practice to learn new skills.	1	2	3	4	5
23	Students need time to talk about their robot and how it is meeting the design brief.	1	2	3	4	5
24	I consider myself to be an innovative teacher.	1	2	3	4	5
25	Learning with robotics has links to other areas of the curriculum in middle schooling.	1	2	3	4	5
26	Pacing student learning is very important to consider when I plan new units of work.	1	2	3	4	5
27	The workload on innovative teachers is exhausting.	1	2	3	4	5
28	I find it difficult to integrate all of the key learning areas into authentic units of work for the students.	1	2	3	4	5
29	I often feel weighed down by the expectations of other teachers to help them with new ideas.	1	2	3	4	5
30	I am concerned about planning challenging tasks that provide the students real opportunities for problem solving.	1	2	3	4	5
31	I use a variety of methods to determine if the learning experiences I have planned and implemented have been successful.	1	2	3	4	5
32	The learning outcomes from working with robotics can have an impact on students' success with outcomes in other areas of the curriculum.	1	2	3	4	5
33	The success of this learning experience with robotics will determine my enthusiasm for undertaking the experience again.	1	2	3	4	5
34	It is important to me that other teachers see that working with robots can have successful learning outcomes for students.	1	2	3	4	5
35	I have been able to talk to other teacher/s about my concerns regarding using robotics with the students.	1	2	3	4	5
36	The experience will only be successful if all students create a functional robot.	1	2	3	4	5
37	Technology assessment instruments should provide information on student processes as well as the products they produce.	1	2	3	4	5
38	I am able to change the focus of my instruction if I find it is not being productive for the students.	1	2	3	4	5
39	The assessment for robotics differs to the assessment for other areas of the curriculum.	1	2	3	4	5
40	The amount of work involved in establishing the robotics lab will be proven worthwhile through student outcomes.	1	2	3	4	5

APPENDIX G

Post-Experience Likert Scale Questionnaire: Student

I am interested in your feelings about the following statements. Read each statement carefully and decide how you feel about it. Please respond to each item as honestly as you can.

Name:………………………… Pseudonym………………….. Date……………

You need to circle a number to show how you feel.

The numbers in the right hand columns mean the following:

1. Strongly agree
2. Agree
3. Undecided or not sure
4. Disagree
5. Strongly disagree

Student Questionnaire

	Statement	Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
1	It is easy to make a robot.	1	2	3	4	5
2	I have the skills required to make a robot.	1	2	3	4	5
3	This is the first robot that I have created.	1	2	3	4	5
4	It is difficult to use the computer program for robotics.	1	2	3	4	5
5	I see myself making more robots.	1	2	3	4	5
6	Robots should be able to do more than one thing.	1	2	3	4	5
7	It is fun creating robots.	1	2	3	4	5
8	My robot will be able to follow the instructions I plan.	1	2	3	4	5
9	It is important to design what your robot will do before you construct it.	1	2	3	4	5
10	I learn more when I can experiment with the robots.	1	2	3	4	5
11	Creating robots is challenging.	1	2	3	4	5
12	I learn more when I work in a group.	1	2	3	4	5
13	The robot I make with my group will be better than the robot I would make alone.	1	2	3	4	5
14	The way that I look at robots has changed.	1	2	3	4	5
15	I want to choose the actions my robot will do.	1	2	3	4	5
16	I become worried when I make mistakes.	1	2	3	4	5
17	Robots should move and act like humans in order to be useful.	1	2	3	4	5
18	It doesn’t matter what a robot looks like, as long as it can complete a task.	1	2	3	4	5

	Statement	Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
19	Robots are more useful if they can talk to you.	1	2	3	4	5
20	I would rather interact with a robot that: looks like a human.	1	2	3	4	5
21	I would rather interact with a robot that: has eyes.	1	2	3	4	5
22	I would rather interact with a robot that: has ears.	1	2	3	4	5
23	I would rather interact with a robot that: has a mouth.	1	2	3	4	5
24	Robots have brains that are similar to ours.	1	2	3	4	5
25	The actions my robot does will show me if I have made it correctly.	1	2	3	4	5
26	I do not get upset when I make a mistake.	1	2	3	4	5
27	I find it difficult to remember instructions when I am doing something new.	1	2	3	4	5
28	I am more confident when I have the chance to correct my mistakes.	1	2	3	4	5
29	You learn more when you fix your own mistakes.	1	2	3	4	5
30	I can solve problems by thinking about them and planning what to do.	1	2	3	4	5
31	I like to talk to someone when I am having difficulty in doing my work.	1	2	3	4	5
32	Everyone in my robotics group should have the same goals.	1	2	3	4	5
33	My experiences with constructing a robot were successful.	1	2	3	4	5
34	I found it helpful to work with a partner.	1	2	3	4	5
35	I was able to solve the problems I had with the robots.	1	2	3	4	5
36	I discovered more about how I learn from working with robotics.	1	2	3	4	5
37	Writing a journal helped me plan what I would do each lesson.	1	2	3	4	5
38	I received helpful guidance from the teacher when I had a problem.	1	2	3	4	5
39	I found it frustrating when I couldn’t solve a problem with the robots.	1	2	3	4	5
40	I could make my own robot to do the things that I want.	1	2	3	4	5

APPENDIX H

Post-Experience Likert Scale Questionnaire: Teacher

I am interested in your feelings about the following statements. Read each statement carefully and decide how you feel about it. Please respond to each item as honestly as you can.
Name:………………………… Pseudonym……………….. Date…………….
You need to circle a number to show how you feel.
The numbers in the right hand columns mean the following:

1. Strongly agree
2. Agree
3. Undecided or not sure
4. Disagree
5. Strongly disagree

Teacher Questionnaire

	Statement	Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
1	The students found it is easy to make a robot.	1	2	3	4	5
2	The students had the skills required to make a robot.	1	2	3	4	5
3	This is the first robotics class that I have taken.	1	2	3	4	5
4	It was difficult for the students to use the computer program for robotics.	1	2	3	4	5
5	I see myself taking more robotics classes.	1	2	3	4	5
6	Robots should be able to do many things.	1	2	3	4	5
7	It is fun creating robots.	1	2	3	4	5
8	The robots were able to follow the instructions the students plan.	1	2	3	4	5
9	It is important for the students to design what their robot will do before they construct it.	1	2	3	4	5
10	Students learn better when they can experiment with robots.	1	2	3	4	5
11	Creating robots was challenging for the students.	1	2	3	4	5
12	Students learned more when they worked in a group.	1	2	3	4	5
13	The robot the students make with their group will be better than the robot they would make alone.	1	2	3	4	5
14	Students like to be able to choose the actions their robot will do.	1	2	3	4	5
15	I became worried when I was unsure about how to answer the students' questions.	1	2	3	4	5
16	Students see robots as being more useful if they respond like humans.	1	2	3	4	5
17	It doesn't matter what a robot looks like, as long as it can complete a task.	1	2	3	4	5
18	Students will see robots as more useful if they can talk like humans.	1	2	3	4	5
19	Students would rather interact with a robot that is humanlike in appearance.	1	2	3	4	5

	Statement	Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
20	Students see robots as having brains that are similar to ours.	1	2	3	4	5
21	The students were able to problem solve the robot's function by looking at its actions.	1	2	3	4	5
22	Students needed lots of scaffolding and practice to learn new skills.	1	2	3	4	5
23	Students needed time to talk about their robot and how it met the design brief.	1	2	3	4	5
24	I consider myself to be an innovative teacher.	1	2	3	4	5
25	Learning with robotics has links to other areas of the curriculum in middle schooling.	1	2	3	4	5
26	Pacing student learning is very important to consider when I plan new units of work.	1	2	3	4	5
27	The workload on innovative teachers is exhausting.	1	2	3	4	5
28	I find it difficult to integrate all of the key learning areas into authentic units of work for the students.	1	2	3	4	5
29	I often feel weighed down by the expectations of other teachers to help them with new ideas.	1	2	3	4	5
30	I am concerned about planning challenging tasks that provide the students real opportunities for problem solving.	1	2	3	4	5
31	I use a variety of methods to determine if the learning experiences I have planned and implemented have been successful.	1	2	3	4	5
32	The learning outcomes from working with robotics can have an impact on students' success with outcomes in other areas of the curriculum.	1	2	3	4	5
33	The success of this learning experience with robotics will determine my enthusiasm for undertaking the experience again.	1	2	3	4	5
34	It is important to me that other teachers see that working with robots can have successful learning outcomes for students.	1	2	3	4	5
35	I have been able to talk to other teacher/s about my concerns regarding using robotics with the students.	1	2	3	4	5
36	The experience was only successful if all students create a functional robot.	1	2	3	4	5
37	Technology assessment instruments should provide information on student processes as well as the products they produce.	1	2	3	4	5
38	I was able to change the focus of my instruction if I find it was not being productive for the students.	1	2	3	4	5
39	The assessment for robotics differs to the assessment for other areas of the curriculum.	1	2	3	4	5
40	The amount of work involved in establishing the robotics lab has proven worthwhile through student outcomes.	1	2	3	4	5
41	The students learned more about how they learn from taking the robotic classes.	1	2	3	4	5
42	I learned more about the effectiveness of my teaching from conducting the robotics sessions.	1	2	3	4	5

APPENDIX I

Pre-Experience Semi-Structured Interview: Students

Interview Outline

Name of Student:	Pseudonym:	Date:

Area	Question
Declarative Introduction	Can you tell me what you think about the things you need to make a robot?
Declarative Knowledge	What materials might you use to make a robot?
	What do you need to know to build a robot?
	What properties does Lego© have that makes it easy to make things?
	What do robots do?
Procedural Introduction	Can you tell me what you think about the steps you need to take to build a robot?
Procedural Knowledge	How do you make a robot?
	Do you need to plan your robot before starting to construct it?
	What computer program might you use to program a robot?
	What would you do if you needed to know something to make a robot and didn't know how?
Conceptual Introduction	Can you tell me what you think about robots?
Conceptual Knowledge	What is a robot?
	How do you think making a robot is different to doing other class activities?
	Where are robots found?
	What would you like to see a robot do?
	What things might you consider in your planning?
Predictions introduction	Can you tell me what you think about how successful you will be in constructing a robot?
Predictions of Success	Could you make a robot?
	What do you usually do if you have made a mistake with your work?
	How would you recognize that your robot didn't know what to do next to complete the task you set?
	How would you know if you had created a successful (good) robot?
Social Introduction	Can you tell me what you think about working in groups?
Social construction	Do you like working in groups? Why/why not?
	What are the good things that can happen when you work in a group?
	Do you like to talk about the problems you are having doing the work with others in your group?

APPENDIX J

Pre-Experience Semi-Structured Interview: Teacher

Interview Outline Teacher		
Name of Teacher:	Pseudonym:	Date:

Area	Question
Introduction	Please tell me about the robotics project.
Pedagogy Introduction	Tell me some things about your pedagogy and robotics
Pedagogy	What preliminary activities will you undertake to prepare students for the activities? Why are they necessary?
	How are you going to structure the class for the robotics lessons?
	How have you worked with other teachers to organize this project?
	What sorts of things would you tell another teacher who has had no experience using robotics in the classroom?
	What preparation (professional development) have you had to prepare yourself for this learning experience?
Goals Introduction	Tell me some things about your goals.
Cognitive goals	What do you expect the students to learn during the experience?
	How will you help the students to reach the outcomes you have planned?
	What areas of the curriculum do you see as being connected to learning with robots?
	How do you think making a robot will be different to doing other class projects?
	What would you do if you a student needed to know something to make a robot and you didn't know how to answer their questions?
Planning Introduction	Tell me something about your planning.
Cognitive Processes	What specific student actions will you be looking for to determine successful involvement in the activity?
	What planning outlines or design brief will the students use to plan and record their learning experiences?
	What specific details would you be looking for in these documents? Why?
	What would you like to see the students do with their robots?
	What general planning needs to be done to prepare the students for this activity?
Assumptions Introduction	Tell me about your assumptions about the students' cognitive world.
Assumptions including meta-assumptions about students' cognitive world	Have the students worked with robots before? Where?
	What other activities have they done that might prepare them for learning with robots?
Predictions Introduction	Tell me about your predications concerning this project.
Predictions of success	How successful do you think your planned learning experiences will be?
	How will you determine this success?
Social Introduction	Tell me about your ideas on students working in social groups.
Social Construction	Do the students like working in groups?
	Do your students work in groups in other areas of the curriculum?
	How will you determine the groups for robotics?
	How will you determine the success of the groups?

Area	Question
Assessment Introduction	Tell me about your assessment for this project.
Assessment	How will you assess learning outcomes/cognition from the experience?
	Does this assessment differ from other ICT project assessment?
	How will you report on learning to interested parties?
	What's more important for long term learning for these students at this stage – the product or the process? Why?

APPENDIX K

Post-Experience Semi-Structured Interview: Student

Interview Outline

Name of Student:	Pseudonym:	Date:

Area	Question
Declarative Introduction	Can you tell me what you think about the things you need to make a robot?
Declarative Knowledge	What materials might you use to make a robot?
	What do you need to know to build a robot?
	What properties does Lego© have that makes it easy to make things?
	What do robots do?
Procedural Introduction	Can you tell me what you think about the steps you need to take to build a robot?
Procedural Knowledge	How do you make a robot?
	Do you need to plan your robot before starting to construct it?
	What computer program might you use to program a robot?
	What would you do if you needed to know something to make a robot and didn't know how?
Conceptual Introduction	Can you tell me what you think about robots?
Conceptual Knowledge	What is a robot?
	How do you think making a robot is different to doing other class activities?
	Where are robots found?
	What would you like to see a robot do?
	What things might you consider in your planning?
Predictions introduction	Can you tell me what you think about how successful you will be in constructing a robot?
Predictions of Success	Could you make a robot?
	What do you usually do if you have made a mistake with your work?
	How would you recognize that your robot didn't know what to do next to complete the task you set?
	How would you know if you had created a successful (good) robot?
Social Introduction	Can you tell me what you think about working in groups?
Social construction	Do you like working in groups? Why/why not?
	What are the good things that can happen when you work in a group?
	Do you like to talk about the problems you are having doing the work with others in your group?
Post-Experience Specific Questions	
Conceptual knowledge	What have you enjoyed most/ least about your robotic experience? Why?
Predictions	What else would you have liked to have done with robotics but did not have the opportunity?
Predictions of success	Do you see yourself continuing with robotics? Why/why not?
Conceptual knowledge	What was the easiest/ hardest part of working with robots?
Social construction	How did you find working in groups? Why?
Procedural knowledge	How did you solve the problems you encountered?
Conceptual knowledge	What did you learn?

APPENDIX L

Post-Experience Semi-Structured Interview: Teacher

Interview Outline Teacher		
Name of Teacher:	Pseudonym:	Date:

Area	Question
Introduction	Please tell me about the robotics project.
Pedagogy Introduction	Tell me some things about your pedagogy and robotics
Pedagogy	What preliminary activities did you undertake to prepare students for the activities? Why are they necessary?
	How did you structure the class for the robotics lessons?
	How have you worked with other teachers to organize this project?
	What sorts of things would you tell another teacher who has had no experience using robotics in the classroom?
	Was the professional development useful for this experience?[9]
Goals Introduction	Tell me some things about your goals.
Cognitive goals	What did the students to learn during the experience?
	How did you help the students to reach the outcomes you had planned?
	What areas of the curriculum do you see as being connected to learning with robots?
	How was making a robot different to doing other class projects?
	What did you do when a student needed to know something to make a robot and you didn't know how to answer their questions?
Planning Introduction	Tell me something about your planning.
Cognitive Processes	What specific student actions did you look for to determine successful involvement in the activity?
	What planning outlines or design brief did the students use to plan and record their learning experiences?
	What specific details did you look for in these documents? Why?
	What would you like to see the students do with their robots?
	What general planning had to be done to prepare the students for this activity?
Assumptions Introduction	Tell me about your assumptions about the students' cognitive world.
Assumptions including meta-assumptions about students' cognitive world	Had the students worked with robots before? Where?
	What activities had they done that best prepared them for this experience?
Predictions Introduction	*Has the project proceeded as you predicted?*
Predictions of success	How successful were your planned learning experiences?
	How did you determine this success?
Social Introduction	Tell me about your ideas on students working in social groups.
Social Construction	Did the students like working in groups?
	Do your students work in groups in other areas of the curriculum?
	How did determine the groups for robotics?
	How did you determine the success of the groups?

[9] Questions in italics indicate questions that have been added to the pre-experience semi-structured interview question outline to gain reflective mental models.

Area	Question
Assessment Introduction	Tell me about your assessment for this project.
Assessment	How did you assess learning outcomes/cognition from the experience?
	Does this assessment differ from other ICT project assessment?
	How did you report on learning to interested parties?
	What's more important for long term learning for these students at this stage – the product or the process? Why?
Post Experience Section	What did they enjoy most/ least about their robotic experience? Why?
	What else would you have liked the students to have done with robotics but did not have the opportunity?
	Do you see yourself continuing with robotics? Why/why not? And the students?
	What did they find the easiest/ hardest part of working with robots?
	How did the students find working in groups? Why?
	How did they solve the problems they encountered?
	What did they learn?

APPENDIX M

Coding for interviews

Coding Mental Models Interviews			
K	Knowledge	PED	Pedagogy
KT	Knowledge Teachers	GOA	Goals
KS	Knowledge Students	CP	Cognitive Process
DIF	Differentiation	MTAS	Meta Assumptions Teachers
DEC	Declarative	MSAS	Meta Assumptions Students
PRO	Procedural	PD	Professional Development
CON	Conceptual	SUC	Success
PRE	Predictions	PX	Previous Experience
SC	Social Construction	SIN	Since
ASS	Assessment	BEC	Because
REP	Reporting	ROB	Robotics
SYS	Systemic Influences	PS	Problem Solving
GI	Gender Issues	FUN	Fun
CRE	Creativity		

APPENDIX N

Category card: digital copy

Student Interview: Ellen		
Card: E2	Social Construction	Code
Page 10	Well it will probably make it better and easier because you won't have to do everything. And you'll probably get your robot done quicker.	KS SC/Pre
Page 10	(Enjoy?) Um, not really. I'd kind of rather work by myself because sometimes when you're in groups people talk too much and you never get things finished.	KS SC/PX
Page 10	Cause if they don't agree they always fight and if you don't, you don't get them finished and stuff.	KS SC/PX
Page 10	(Friends?) You might like forget about your robot and talk with someone else, about what did you do on Saturday or something. No, it's just because they, we get too occupied on things that we've already done and stuff.	KS SC/PX
Page 11	(Good) Um, it's easier because everything happens at once. You don't have to do it in segments and parts. There can be a person working on each part of the robot's body.	KS SC/Pre
Page 11	(Problems?) Yes, cause it helps it and they might know how to fix it. And it's better that you communicate.	KS SC/Pre
Page 11	(Not cooperating) Um, well we still work as a group. You just keep on doing stuff that you're meant to do; the part of whatever you're meant to do. Um, like someone, they have to agree on that so they can put it together. So you can make those two parts. You might like change your part and do something else.	KS SC/ PX
Links	Card P2; Ji2; J2; S2	

APPENDIX O

Longitudinal Semi-Structured Interview (March 2006): Student

Longitudinal Interview Outline: Students

Name: Pseudonym: Date: March 2006

Area	Longitudinal question
Declarative knowledge	You mentioned fun when you talked about robots. Do you still feel that doing robotics is fun?
	Do girls and boys work differently with robotics? How? Why?
Procedural knowledge	Is it important to follow you goals or plans when you do robotics? What if you change them? Why would you change your plan?
	Is being able to problem-solve an important skill with robotics? Why?
	What do you do when you problem solve?
	Were the journals helpful during your experience? Why/why not?
	Do you think you have the skills to create robots?
Conceptual knowledge	How does doing robotics allow you to be creative?
	Do you ever know all you need to know about robotics? Is it different in that way to other areas of learning?
	How do robots think? How does this compare to how we think? Why is it different?
Social construction	Do all of the children work the same way during robotics? How do they work differently? Does it matter if people work differently? How does it help/hinder?
	How does working in a group help you learn? What types of things do you learn?
	Do you think you create better robots working in a group or on your own? Why?
Forum issues	What did you enjoy most/least of the robotics experience? Why?
	Are you working with robotics now? Why/why not?
	What did you learn about yourself as a learner from the experience?

Area	Longitudinal question
Assessment	What forms of assessment did your teacher give for the robotics program? Was it suitable to show what you had learned? What forms should be given for robotics? Why?
	Is it important for students to know what the teacher is looking for specifically when doing assessment tasks?
	What level of assessment (medium, hard, easy) should be given and why? Should you be made to problem solve during assessment? Should it be a challenge? Would it worry you if you didn't get it completed?
	What can you learn from doing assessment? How can you use that knowledge?
	How does working in a group help you learn? How does it help when you are being assessed?
	What emotions do you feel when you are being assessed? What thoughts do you have? Why? Does it depend on the type of assessment? Some of you mentioned being scared. Why? Would you perform better if you weren't scared? Was does being scared mean/do?
	Do different types of assessment suit different students? How?
	Should assessment occur just at the end of your experience? Throughout? How would you do this and why? What if you needed more time to finish the assessment? Should everyone be at the same stage at the same time? Why?
	What's the best way of showing others (parents/administration) what you have learned? Should there be a variety of ways to suit all learning styles?
	What might happen if report cards were abolished? Why might we keep them?
Cognitive Process	Can you tell me the impact of sharing the equipment on how you learn? How can this be addressed?
	Creativity: You mentioned creativity during the forum interview. What is creativity? How does that impact on your learning and what you think about learning?
	Fun: You mentioned fun during the forum interview. What is fun in learning, and how does that impact on your learning and what you think about learning?
	How do you/teachers determine the confidence students have in doing tasks?
	Did you see the robotics experience as a challenge? Is a challenging activity worthwhile? Why/why not?

APPENDIX P

Longitudinal Semi-Structured Interview (March 2006): Teacher

Longitudinal Interview Name: Pseudonym: Pamela 16 March 2006	
Area	**Longitudinal question**
Pedagogy	Has the experience informed your pedagogy – generally/specifically? Why?
	In your journal you mentioned gender issues. What are your observations about how boys and girls work with robotics?
	Any other teachers taking up the activity? Why/why not?
	What are the real outcomes for the teachers after working with robots?
Cognitive Goals	Have your goals changed? Why?
	You said you were on the right track after the forum. What responses now to that? How would it be run/is run?
	Has this experience informed your pedagogy and understanding of student cognition in other areas of the curriculum?
Cognitive Process	Learnt and fun – two words that were used in response to forum. What thoughts on that now.
	Creativity: You noticed that they had clued into creativity during the forum interview, what views do you have on creativity and how does that inform your pedagogy and or the cognitive process?
	Do you think the students have the skills to create robots? Do students learn more when they have the opportunity to fix your own mistakes? Why? Do they worry when they make mistakes? How should this be dealt with in the classroom?
Assumptions including meta-assumptions about students' cognitive world	How do the students think robots think? How do they compare this to how we think? Do they see it as different? What changed during the experience?
	We make assumptions about what students know. Are we informed enough of their cognition when commencing new activities? If not, what can we do to improve our understandings?
	What are the real outcomes for the students after working with robots?
Predictions of success	What makes an activity such as robotics too difficult to undertake? Did the students see the robotics experience as a challenge? Is a challenging activity worthwhile? Why/why not?
	What emphasis did the students place on successfully completing each step? Was it more of an issue for some? How do you deal with different personalities?

Area	Longitudinal question
Social Construction	Can you tell me the impact of sharing the equipment on student learning? How can this be addressed?
	Do you think students create better robots working in a group or on their own? Why?
	Feedback from forum – partners. Distributed cognition. It's role. How manage if student worked alone.
	If divergent thinkers – how do we assist with social constructivism/distributed cognition for all students?
	Does too much fluidity of group structure enhance/distract from learning?
Assessment	You stated that students feel the pressure of assessment. Can you expand on that?
	Given your experiences and the feedback from the students in the forum, how would you structure your assessment for future robotics experiences? What form would it take? Why?
	Teachers understand the differences in personality and learning styles. Students mentioned: speed/quality/confidence – These inform our teaching but how do they inform assessment? Are time frames for assessment important?
	Setting up to succeed – is this a valid way of approaching assessment? Why or why not? Is it important for students to know what the teacher is looking for specifically when doing assessment tasks?
	The forum displayed students' awareness of all moving at same time – along a timeline that is expected? Why may that not be valid? How do we work with the current climate of point in time assessment?
	Specific things that current assessment fails – point in time vs journal. So why is the change in attitude evident in students' journals so important for teachers? Were the journals useful?
	Digital portfolio – benchmarks set by you – is this a guide? Does it relate to curriculum document – then if so – does this make reporting easier/more valid for all participants? What are some of the drawbacks?
	In the forum you said that we make assumptions about what kids know about assessment. What are the assumptions? How do we counteract that? Why should we?
Assessment	You noted that assessment can take the fun out of learning due to the pressure on students. Does valid assessment take the fun out of learning? How do we counteract this? How should teachers involve/inform parents in this?
	What might happen if report cards were abolished? Why might we keep them?
	What can the students learn from doing assessment? How can they use that knowledge?
	If students can inform us of their own learning – how do we get this information? How do we guide them/when/how often/what age? Bench marks/reporting. The students discussed the degrees of understanding on a sliding scale – is this valid? How would you show this? How would they inform the assessment? What's the best way of showing others (parents/administration) what the students have learned? Should there be a variety of ways to suit all learning styles?
	What are some of the advantages/drawbacks in enabling students to inform assessment? (Focus Group – Sprocket)

APPENDIX Q

Longitudinal Semi-Structured Interview (October 2006): Student

Longitudinal Interview Outline: Students	
Name: Pseudonym:	Date: October 2006
Area	**Longitudinal question**
Procedural knowledge	Is it important to plan how you do a project? Why?
	Are problem solving skills important to your learning? Why?
	When do you apply problem solving skills? Why? How do they help?
	Do you write in a journal? How does journaling help?
	How do you know what steps to take to complete a new task? How do you best learn the steps to take?
Conceptual knowledge	What activities do you like to do? Which ones help you learn the most?
	Looking back on robotics – did problem solving to build and program a robot help you with any other learning area? Maths? English? Science?
	What do you do when you are learning something new? Does seeing how 'not' to do something help you learn? Why? Should teachers show you the mistakes that can be made and explain why you shouldn't do something a certain way?
Social construction	Do you work differently in a group to how you work alone? Why?
	How does working in a group help you learn? What types of things do you learn?
	How does working in a group hinder your learning? Do you use different strategies to get tasks done?
Robotics	Have you done robotics this year? Do you remember how?
	What did you learn about yourself as a learner from the experience?

Area	Longitudinal question
Assessment	What were your thoughts on the year seven testing you did this year? What do the tests say about you as a learner? Are there other ways of showing what you've learned?
	Do different teacher assess you differently? How do you know that they are different? Does it make a difference to how you learn?
	Level of difficulty with assessment – medium etc Problem solving – or something done before Is completing it important
	Does doing assessment help you learn? What?
	How does working in a group help/hinder assessment?
	When do you perform at your best? Does being able to talk about it help? Can you explain what you are doing?
	Different types. Different times More time to finish
	Can you explain your report card and what it means/tells about you? Is there another way of doing this? Do you help your teacher write it?
Cognitive Process/Pedagogy	Do teachers teach in different ways? Which ways? Does it make a difference to you as a learner? What did Paris do that helped/hindered your learning?
	Do you think about your own thinking? Have you been taught to do this? How does it help you if you do?
	Fun: You mentioned fun during the forum interview. What is fun in learning, and how does that impact on your learning and what you think about learning?
	How do you/teachers know if a student is confident in doing tasks? What does confidence mean? Is there only one way of doing things? What do you do if you find a new way of doing something?
	Did you see the robotics experience as a challenge? Is a challenging activity worthwhile? What makes an experience a challenge?

APPENDIX R

Longitudinal Semi-Structured Interview (March 2006): Teacher

Longitudinal Interview Outline: Teacher

Name: Pseudonym: Pamela Date: October 2006

Area	Longitudinal Question
Pedagogy	Have you worked with robotics this year?
	Since commencing robotics, have you changed the way you? . organize the activity . . assess the activity
	Any other teachers taking up the activity? Why/why not?
	What are the real outcomes for the teachers after working with robots?
Cognitive goals	Have your goals changed? Why?
	Do you think that the students alter their learning style in acknowledgment of your pedagogical practice? How? Do they transfer skills/strategies to other areas?
	Has this experience informed your pedagogy and understanding of student cognition in other areas of the curriculum?
	Do you incorporate successful processes the students use into subsequent lessons?
Cognitive Processes	What specific student actions did you look for to determine successful involvement in the activity? Did you incorporate any of these strategies into your teaching?
	What planning outlines or design brief did the students use to plan and record their learning experiences?
	What specific details did you look for in these documents? Why?
Assumptions including meta-assumptions about students' cognitive world	How well did you understand the students' cognitive processes before commencing the activities? Do you use metacognition with the students? How?
	What are the real outcomes for the students after working with robots?
Predictions of success	Has the project proceeded as you predicted?
	How successful were your planned learning experiences?
	How did you determine this success?
Social Construction	How did you manage the groups this time? Divergent thinkers.
	What strategies do you see them use successfully in group work? Do you introduce any of their strategies to other groups?
Assessment	How did you assess learning outcomes/cognition from the experience? Have you changed your practice? Why?
	How does your philosophy of assessment impact on the students? Do they learn how to respond specifically to your methodology?
	Digital portfolio – benchmarks set – is this the guide? Does it relate to curriculum document – then if so – does this make reporting easier?
	Do they learn how to show what they have learned from doing an experience such as this? Is it still product based in their view?
	How do we determine creativity? Is it important to do so?
	How much does individual personality impact on assessment? Do you talk about success/assessment?
	Do you use negotiated assessment? How is it beneficial to the students? Other stakeholders?
	What did you learn from the students?

APPENDIX S

Researcher's journal entry: Stimulated Recall decision

08/5/05

What are the theoretical parts of the mental models?
How re they working out in practice?
MM [mental models] about task, process, partnerships, teacher etc.

What MM functions are being specifically demonstrated here?
Does the task break down because they don't have the required knowledge or exp [experience] yet?

What of 'don't knows'? Lit [literature] suggest something?
Could adapt meth [method] – next time to enable students to explain what they were doing – new way to look at SR [stimulated recall].

10/5/05

Process of constructing/program showing procedural (explanatory) MM in all students' interviews. Little use of PS [problem-solving] (predictions) MM evident? Indicates what?
Social Const MM evident – lone scientist – are they working together??

16/5/05

SR interviews are not providing the recalled thoughts and feelings required for comparative study.
Decision to alter methodology of the SR interviews with students by asking "What were you doing?" or stating what they were doing prior to asking the questions "What were you feeling/thinking?" The supportive theory for this change comes from observation of the children's willingness to discuss their actions as indicated in the SR1 interviews.

APPENDIX T

Page from the tattered pink journal of the researcher

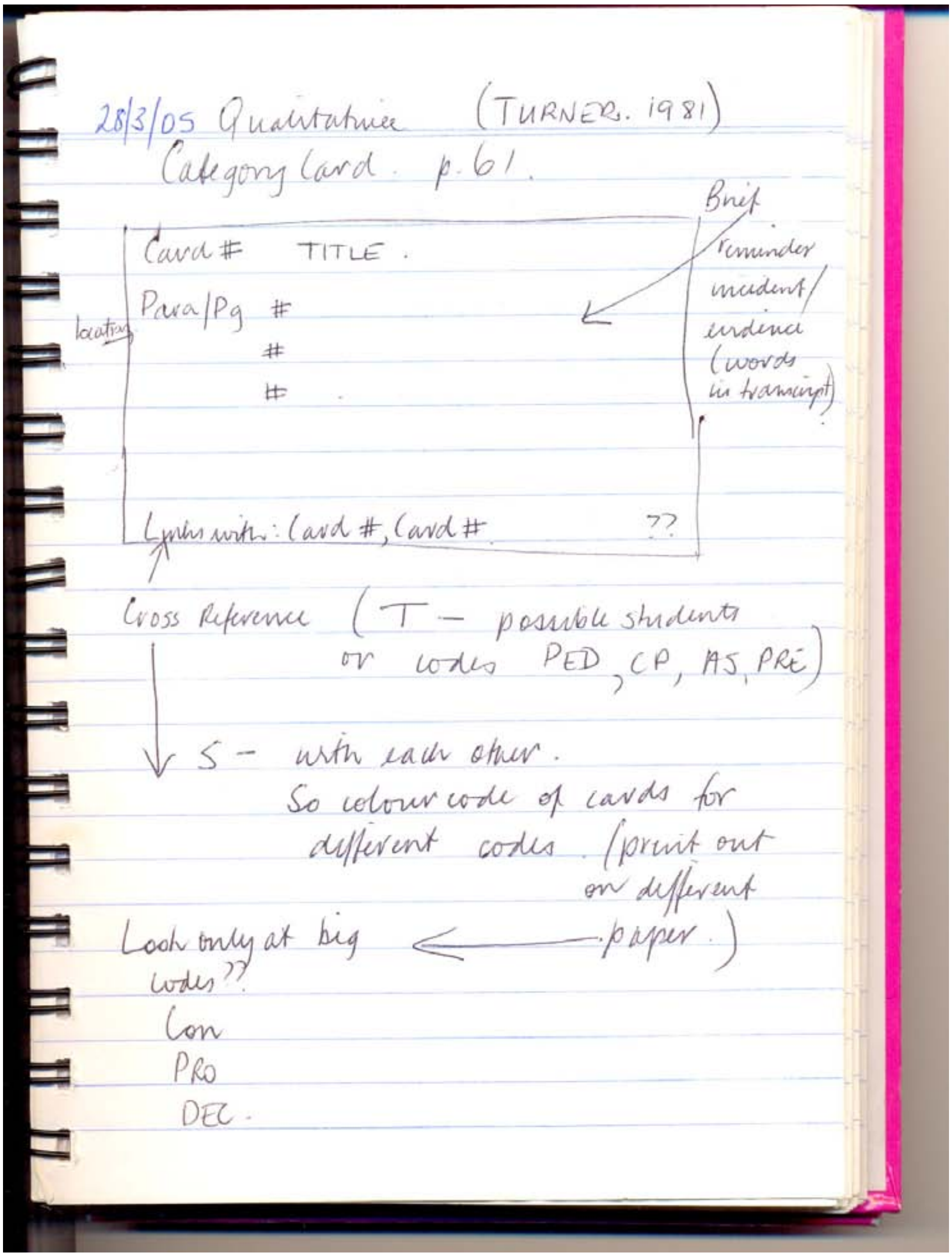

Figure 1: Page from researcher's journal 28 March 2005 depicts planning for analysis of research data including codes, category card layout, cross-referencing notes.

APPENDIX U

Teacher Journal example of transcript

An example of how Pamela used her journal to record the impact that the journals were having seven weeks into the learning experience, was recorded on May 3, 2005:

> They are beginning to use their journals. There was no resistance to staying a little later to fill them in. I don't think their goal setting ability is mature yet! They did not link their reflection to their goal either. We need to review relating their reflections to their initial goals. (Pamela, In-Action Journal, 3 May 2005).

Pamela's comment about the students' "goal-setting ability" enabled her to review the use of the students' journals thereby providing an authentic teaching opportunity. Pamela's perseverance in using the students' journals must have proved worthwhile when she recorded on 14 August, 2005, "They are beginning to get the idea with their journals" and then on 29 September, 2005, "Their journal writing has become a firm part of their routine now. They give good insight into where each student is at, and how they are feeling" (Pamela, In-Action Journal, 2005). Such anecdotal observation may be lost if not recorded on a regular basis.

APPENDIX V

Teach-Back Directives

Instructions

Verbal Instructions given to participants in the Teach-back data collection episodes in 2005

Time of Instruction	Content of Instruction
One week before Teach-back episode	You will be required to teach another student about robotics. In one week's time you will have 30 minutes to teach them enough of the program so that they can build and program the robot to complete a simple task. You will decide what task the robot will need to complete. At the end of the 30 minute lesson, the student should feel confident that they could construct and program the robot on their own.
Five minutes before Teach-back episode	This is a teach-back session between [teacher pseudonym] and [pupil pseudonym] held on [insert date] and the time is [insert time]. I'm going to read some dialogue first of all so you understand what is going to happen today. [Pupil pseudonym], you are here today to learn how to use the robotics kit. [Teacher pseudonym], you are here today to teach [pupil pseudonym] how to use the robotics kit. I will provide no direction as to how this lesson is to proceed. The lesson will proceed under the guidance of [teacher pseudonym]. She/he will decide the skills and knowledge required for you to be able to interact successfully with the kit. [Teacher pseudonym] has a half hour to conduct the lesson. Your goal, as a teacher, [teacher pseudonym], is to enable [pupil pseudonym] to gain a working knowledge of robotics. I'll give you five minutes now to think about how you are going to conduct the lesson and I'll tell you when it's time to start.

Interview Scripts

Questions for Novice Pupil

How confident do you feel, after having this experience, to come in and work with the robotics kit on your own?

Can you please give me a percentage of the success that you think you might have?

Why did you select this percentage?

Questions for Expert Teacher

How confident were you that you covered all the things you need to know so that [child's name] has a working understanding of robotics?

Why did you choose that way of teaching?

Is that the way you were taught?

Which way of learning robotics works best for you?

How would you assess whether she was competent at doing robotics?

How do you feel about the depth or completeness of what you showed her today?

If you could improve your teaching method, what would you do?

So looking back over what you did today, how confident are you that you showed her as much as she needs to know to be proficient?

APPENDIX W

A. Focus Group Interview Introduction

This is a forum that is being held with the four student participants on Tuesday 15 November 2005 and this forum is being held after the assessment activities that the students did with each other on Monday 14 November 2005. Now a forum is like a group interview, where I'll be asking questions and, at times, I might ask you directly to answer a question. Other times I might ask, "Does anybody have anything more to say?" or, "Does anyone have anything else to say about a certain topic?". That's when you're welcome to give your opinion. Now, because it's your opinion, it's not anyone else's opinion, thus, there are no right or wrong answers. Everything you think and feel is of value. And this is your chance to express that.

The first thing that we are going to be looking at is what happened yesterday. I'd like you to take your minds back to what happened yesterday and think about when you were the teacher or the assessor, the person doing the assessment. What I'd like you to think about is (1) how did your thoughts about robotics guide you in determining what you were going to give the other person to do? And (2) how did your thoughts of robotics guide you in deciding what you were going to give them as a test?

Note: The fact that two questions had been asked in quick succession in the opening part of the interview may have had some influence on their ability to respond succinctly due to the perceived complexity or even ambiguity of the probe. A retrospective review of the opening statement and questions poses some consideration for future focus group interviews for this interviewer.

B. Focus Group Interview Outline

Note: While most questions were pre-arranged prior to the conducting of the assessment task, their content and focus was also informed by what had been observed during that session. The students' interactions and reactions helped to define what was included in the questions because it provided the context for authenticity.
Other questions were evident in the interview transcript as the interviewer followed particular items of discussion raised by the students.

Specific assessment questions on experience from the day before.

How do you see robotics?
How did your thoughts of robotics guide you in deciding what you were going to give as a test?
What were you looking for when you set your tasks?
When you were the learner what emotions or the thoughts were going through your head as you were working through the task?

Did you feel comfortable in the situation yesterday doing what was required of you?
… as the assessor? … as the learner being assessed?
What did you do when you were the assessor or the person giving the test when something wasn't going quite right for the learner?
If you were the teacher and that was the assessment task that you had to tell parents about, how would you record what happened yesterday?
Would you like someone to write something down about what you did yesterday?
Would that show your problem solving skills?

General assessment and reporting questions.

Would what you did yesterday be a good way of assessing you?
How you would like to be assessed for robotics?
How would you report on robotics? How would it look?
Is that the same for everything that you do?
What sort of experiences have you had so far on testing?
How much help is it okay to give when you're testing somebody?
As an assessor, how do you decide when to step in and give help and when not to?
If you've got to give too much help to someone, what is that telling you?
How do you feel when you're being assessed on something and you really don't know how to do it?
When you can't do a task, how you feel about being assessed? What goes through your mind?

General questions about learning and demonstration of learning.

Do you only have a feeling of achievement when you've actually completed something?
Is the completion of the whole project essential for you to feel like you have learned?
What do you need to do to show that you've been successful at learning?
What could you do that really show what you've learned?
Do you think the person you worked with throughout the year has a pretty good understanding of what your strengths and weaknesses are?

Summary question on experiences of learning in robotics.

If you looked back now before you even started robotics, can you remember what you thought would happen this year?

APPENDIX X

Example of Ellen's and Jayne's interviews in May 2005 and in July 2005

The following extracts are from Ellen's and Jayne's experience with programming the robot in both the first and second stimulated recall episodes. They had experienced success in their first programming activity, but their second episode proved more difficult as they were attempting a more complicated robot construction and program. The video clips that prompted Ellen's responses were during a period where the programming proved confusing for both of the students. Table 1 shows the extracts from both stimulated recall episodes for Ellen. Table 2 shows extracts from interviews with Jayne, who showed less variation in her responses from one interview to the next.

Table 1 Segments of initial Stimulated Recall Interviews with Ellen, May and July 2005.

Participant: Ellen	
Stimulated Recall Episode 1 May 2005	Stimulated Recall Episode 2 July 2005
What were you thinking? <u>I think I was looking at the teacher.</u>	What were you doing? <u>She [Jayne] was showing me where to click and everything.</u> What were you thinking while you were doing that? **That she didn't really need to do that because like there was a running arrow pointing to there in the computer!** What were you feeling? **I felt okay.**

Note. All segments of the section of interview transcript have been included. No video transcript is included.
Normal script = questions by interviewer;
Bold script = there and then thoughts of participant;
<u>Underlined script</u> = explanation of what participant "did" during activity; and
Italicised script = "here and now" thoughts of participant giving rationale or explanation.

Table 2 Segments of initial Stimulated Recall Interviews with Jayne, May and July 2005.

Participant: Jayne	
Stimulated Recall Episode 1 May 2005	Stimulated Recall Episode 2 July 2005
What were you thinking when you were moving to your station? I thought that **it would probably be hard** and that **I wouldn't be able to do it,** but *when I got there it was easy* and I got up to Pilot 2. So that was really two different places? Yes. When you were moving there, what were you thinking? I was thinking that **it might be hard** but *when I got there it was actually easy*. That's what you thought then? Yes.	What were you doing there? Going through the steps. To see if it would work. You were looking up at the screen and Pamela asked you, "Is it the same as that one?" What were you doing with the RCX in your hand and the one on the screen? Seeing it they were the same and if we needed to put anything on it or take anything away. Okay. And what were you thinking when you were doing that? It was **quite complicated because it kept showing us stuff that we didn't have** so we just took if off and built it again.

Note. All segments of the section of interview transcript have been included. No video transcript is included.
Normal script = questions by interviewer;
Bold script = there and then thoughts of participant;
Underlined script = explanation of what participant "did" during activity; and
Italicised script = "here and now" thoughts of participant giving rationale or explanation.

APPENDIX Y

Extract from Transcript of video capture of lesson with Pamela, Jim, and Sam, July 2005.

Source	Details
Video	Sam continues with the program while Jim watches from the floor. Sam and Jim listen to the instructions while Sam clicks the mouse. The program asks for a timing change.
Pamela	So how long will that motor run for?
Sam	One second.
Pamela	Then it will stop. Then it will switch off.
Video	The program tells them they are finished and tells them to place their robot on the activity pad that came with the kit. Then it tells them to run the program. Both boys look at the robot and Jim leans over to press a button on the robot. Sam continues to sit at the computer. The voice tells them how the robot will move [the robot will move forward until it senses the black line and then it will turn left and move for one second]. The robot does not move.
Pamela	Okay you've got to start with the dot [a particular place on the activity pad that accompanies the robotics kit for this activity]. Yeah. Is the infrared coming down onto the page?
Sam	Yeah.
Pamela	What's that?
Video	Pamela points to a part of the robot.
Sam	The light sensor.
Pamela	The light sensor. That's the thing that actually senses the change. Now which way is it going to turn first of all?
Jim	That way.
Video	Jim indicates left.
Pamela	Mmm. Turn it on. See if it actually . . . did you downloaded it yet?
Jim	Yeah.
Video	Jim presses a button and the robot goes in a circle. [The robot has not done the action that it was supposed to do.]

APPENDIX Z

Glitch in the Lego™ Dacta equipment and Robolab™ software

The "glitch" in the programme, referred to by Pamela in the transcript, had been experienced by several groups of students and was, indeed, a design fault that required the removal of a sensor on the completed robot in order for the programme to be successfully downloaded. In other words, the students had correctly constructed the robot and programmed the software, but were unaware that the programme would not reach the robot via the infra-red due to obstruction by the sensor. The students would have had no way of knowing that their work on this particular programme would be challenged by the design fault. Pamela had seen other students falter at this problem and had been able to trouble-shoot the problem herself before stepping the students through the correction.