THE ROLE OF STRATEGIES IN COMPLEX TECHNOLOGY PROBLEM SOLVING

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DECLARATION

The work presented in this thesis is, to the best of my knowledge and belief, original, except as acknowledged in the text. This thesis contains no material which had been submitted, either in whole or in part, for a degree at this or any other university.

Stephen Richard Turner
1st September, 2011
ABSTRACT

Two issues are addressed in this thesis. Firstly, the nature of technological problems and the ways in which they differ from everyday problems are explored. It is argued that technological problems are complex and ill-defined and that these characteristics determine that specific problem-solving strategies are required to resolve these problems successfully. The second issue addressed is the manner in which pre-service technology teachers solve technological problems including the strategies they employ to solve them.

The results of the empirical studies in this thesis reveal that problem-solvers, while employing expert-like strategies in one domain, apply a combination of both expert and novice-like problem-solving strategies (sometimes referred to as heuristics) when they are confronted with an unfamiliar domain or new problem type. It is argued that this phenomenon occurs when the problem-solver has exhausted the knowledge and skills acquired in previous problem-solving events and the transference of this experience to the new domain or problem type ceases. As a result, the problem-solver reverts to novice-like heuristics such as trial-and-error in an effort to resolve the problem or its sub-problems. However, this leads the problem-solver to switch direction numerous times, diverting their efforts, in many cases, towards low priority issues and unproductive outcomes. It is argued that systemised strategies such as Advanced Systematic of Inventive Thinking (ASIT), guide the problem-solvers activities toward more productive and rewarding outcomes leading to plausible solutions being generated from within the problem elements thereby simplifying the problem-solving process.

The introduction of Technology Education courses in schools as a result of the Australian National Curriculum Corporation’s draft National Curriculum (1994) created the core Key Learning Areas (KLA’s) of Technology Education. Technology Education was intended to be mandatory in schools from years 1 to 10 throughout Australia. The decision by the Australian National Curriculum Corporation (1994) to focus learning activities in Technology Education around creative problem-solving with students responding to a design brief was of significance. However, state
education authorities around the country interpreted the direction of the Australian National Curriculum Corporation as they saw fit and as a result there are some variations in what has been implemented across states.

The Queensland Studies Authority (QSA) Technology Syllabus (2003) for Years 1 to 10 was released in 2003 and was intended to develop students’ creativity and problem-solving skills. This represented a significant change in the direction of school technology classroom activities which had previously been focused on technical manufacturing skills rather than creative problem-solving and related strategies. To accommodate this new direction and focus fundamental changes were needed to the content and delivery of pre-service Technology teacher education courses. It is the aim of this thesis to contribute to knowledge of technological problem-solving and the development of improved problem-solving teaching strategies that address this deficit in the Technology Education classroom.

It is argued that ill-defined problems are increasingly the most common problems that people face in daily life. Yet despite the frequency of ill-defined problems they are the least researched and understood. In addition, it is argued that the study of ill-defined problems has been less successful and yielded less fruitful results than the study of well-defined problems.

It is also argued in this thesis that a lack of knowledge and understanding of the strategies for solving complex ill-defined technological problems and of the related strategies for teaching technological problem-solving exists in schools and tertiary education. It is these gaps in knowledge that are addressed by this thesis.

This thesis focuses on four related areas, including: (a) detailed studies of the manner in which pre-service Technology teachers solve complex design problems, (b) the effect of structured problem-solving strategies and the solutions generated when applied to ill-defined technological problems, (c) the manner in which pre-service Technology teachers direct the deployment of cognitive procedures, and (d) the generation of plausible solutions to ill-defined technological problems.
This thesis contributes to the understanding of technological problem-solving and the application of structured strategies, such as the Advanced Systematic of Inventive Thinking (ASIT) to solve these problems. It is argued that this knowledge may have implications beyond the Technology pre-service teacher classroom due to the development of a new range of teaching approaches based on problem-solving and improved outcomes in the Technology Education classroom in both schools and tertiary settings. Further research is needed to establish if the findings of this thesis may be extended beyond the Technology classroom to other aspects of education and curriculum.
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CHAPTER 1

1 INTRODUCTION

This thesis examines two related issues. The first is the nature of technological problems and the ways in which people solve them. It is argued that technological problems are complex and ill-defined (Robertson, 2001). Robertson claims that ill-defined problems are those where many of the aspects of the problem are vaguely stated and require specific strategies for resolution. The second issue is the way pre-service Technology teachers solve technological problems and the strategies (sometimes referred to as heuristics) they use to both solve them and develop strategies to assist school students to solve them. It is argued that currently, there is a lack of knowledge about strategies for solving technological problems and of the related strategies for teaching technological problem-solving in schools.

1.1 Context

In 1994, the Australian National Curriculum Corporation produced a draft national curriculum (Curriculum Corporation, 1994) based on eight Key Learning Areas (KLA’s) that were intended to be mandatory from years 1 to 10 throughout Australia. For the first time, Technology was included as a core area of study. Possibly of more significance was the decision to construct the learning activities in Technology Education around creative problem-solving, with students responding to a design brief.

State governments are responsible for the provision of education in Australia so each state implemented the KLA’s as they saw fit. This determined that there would be some variation in terms of what was implemented across states.

Queensland developed their Technology syllabus from the National document in 2003. The Queensland Studies Authority (QSA) Technology Syllabus (2003) for Years 1 to 10 states that through working technologically ... provides opportunities for students to practice critical and creative thinking, problem-solving and decision making when meeting design challenges (QSA, 2003, 10). However, these learning
activities do not appear to be adequately addressed in Technology classrooms. As a result, the Technology learning activities in Queensland schools are typically product-based and the learning activities are usually presented in the form of a teacher-directed job sheet. The job sheet usually specifies the precise nature of both the product to be produced and the processes to be employed by students when producing the product. Thus, learning is essentially about attempting to reproduce a skill and problem-solving is limited to interpreting the demands of the skills. Creativity does not appear to have a place in either the process of producing the product or in its final form.

In contrast to the teacher-directed job sheet approach, a design brief is often used in the Australian Technology classroom to identify a real human need or problem. The design brief contextualises the need/problem and outlines any functions and limitations that are to be included or considered by the Technology student. The difficulty and complexity of the design brief is governed by the teacher, who introduces skills and knowledge thought to be appropriate for the pedagogical development of the students and the successful completion of the design challenge.

As a result of the ill-defined nature of technological problems and the designing process, students will encounter a variety of anticipated and forecast or otherwise unexpected technological problems. These technological problems need to be solved in order to complete the design challenge successfully. However, observations of practice reveal that in both the Industrial/Manual Arts and the Technology (sometimes referred to as Design and Technology) context, teachers spend little or no time teaching structured or systematic problem-solving strategies such as problem finding, problem-solving, problem forecasting or problem analysis or developing the problem-solving skills of their students.

As early as 1984, Bransford and Stein maintained that many teachers were unaware of the problem-solving process despite using such processes themselves. As a result it is argued by Bransford and Stein (1984) that problem-solving is not learnt in schools because it is not taught in schools. However, more recently Warner (2001) found: A core group of progressive teachers, approximately 40 from a total of 1150 [in Queensland] have chosen to implement a school based technology curriculum [that
incorporates problem-solving strategies] (in Barnes and Chester, 2002, 17). This number may have increased in recent years; however, it is one of the goals of this thesis to contribute to the understanding of technological problem-solving and develop improved problem-solving teaching strategies aimed at addressing the deficit of a systemised design problem-solving approach being taught in the Technology Education classroom.

A cognitive approach is taken in this thesis to explain the nature of technological problems, the process of technological problem-solving and the role strategies play in the problem-solving process. A cognitive approach has been adopted since cognitive research (Anderson, 1993; Newell and Simon, 1972) has been able to provide explanations of the structure of many aspects of problem-solving, and of processes for solving problems.

1.2 Statement of the Problem
This thesis addresses three key questions: firstly, what is the nature of technological problems, secondly, how do people solve technological problems, and thirdly, what strategies for solving complex technological problems are used by pre-service technology teachers?

Queensland school students encounter design based problems through a number of study areas, including Technology Studies, Engineering Technology, Senior Graphics, Aerospace Studies and the Technology Syllabus Years 1 to 10. These syllabus documents require students to be introduced to problem-solving and innovation through the use of design challenges. Design challenges are outlined by the Technology Syllabus Years 1 to 10 as ... situations, problems or tasks that have a technology demand - that is, they are challenges requiring students to make cognitive and practical responses that draw on their technology [sic] knowing, practices and dispositions (QSA, 2003, 2). To be successful this practice demands that students develop a clear understanding of the concepts and methods of problem forecasting, problem identification, problem finding and problem-solving, including the natural evolution of product design and technology and a practical approach to product and process development.
However, to implement and teach these strategies effectively, Technology teachers are also expected to have a greater understanding of problem-solving and the development of problem-solving skills. Although this is the expectation of teacher employing authorities in Queensland, a review of relevant syllabus documents, supporting resources and current Technology teacher training courses was unable to find evidence of these requirements being fulfilled.

1.3 Contribution of the Thesis

This thesis is concerned with understanding the problem-solving strategies that pre-service Technology Education teachers employ to solve technological problems. The intention is that a greater understanding of technological problem-solving and the strategies used to solve these problems will lead to the development of a new range of problem-solving teaching approaches and improved outcomes in the Technology Education classroom. The contribution of this thesis is focused on four areas. Firstly, by performing a series of detailed studies into the manner in which Technology student teachers solve complex design problems, this thesis adds to our understanding of structured and unstructured strategies and their impact on the deployment of cognitive procedures and the outcomes generated. Secondly, this thesis contributes to our understanding of the effect of structured problem-solving strategies and the solutions generated when applied to ill-defined technological problems. Thirdly, this thesis makes a contribution to our understanding of structured problem-solving strategies and the manner in which they direct the deployment of cognitive procedures and the generation of plausible solutions to ill-defined technological problems. Fourthly, this thesis makes a contribution to teaching and learning by providing possible practical ideas and concepts that can influence the development and application of Technology teaching practice.

The contribution of this thesis to theory in terms of the impact of structured problem-solving strategies, such as the Advanced Systematic of Inventive Thinking (ASIT), may have implications beyond the Technology classroom and technological problems. It is expected, therefore, that further research may lead to extending the findings of this thesis beyond the ill-defined problems of the Technology classroom to other aspects of education and curriculum.
1.4 Structure of the Thesis

The main arguments of this thesis are that technological problems are complex and ill-defined and that Technology teachers (and students) require strategies in order to solve these problems successfully. The thesis is structured in the following way. Firstly, this chapter is devoted to identifying the research problem and locating it within the cognitive research literature on problem-solving and on problem-solving strategies. It outlines the relevant literature and identifies gaps in that literature on problem-solving and specifically on the processes by which complex, ill-defined technological problems are solved and the strategies used to solve them. Thus, Chapter 1 describes the context of the study and leads into the review of problem-solving literature in Chapter 2 and the literature on problem-solving strategies in Chapter 3. Chapter 4 comprises a description and justification of the research methodology employed to examine the predictions from Chapters 2 and 3. Chapters 5 and 6 report the findings of Studies 1 and 2 while Chapter 7 discusses the findings and their theoretical and practical implications. Chapter 7 concludes with suggestions for further research. The following sections explain how each of the remaining chapters contributes to the thesis.

In Chapter 2 the literature on the nature of problems and of problem-solving is reviewed and an argument is advanced that technological problems are complex and ill-defined (Newell and Simon, 1972; Robertson, 2001) and require particular strategies to be employed by the problem-solver to achieve resolution. Information processing theory (Anderson, 1993; Middleton, 1998; Newell and Simon, 1972) is used to explain the processes people use when solving problems. The aim of the chapter is to locate the thesis in the cognitive literature and establish the need for people engaged in solving technological problems to employ particular strategies to achieve success.

In Chapter 3 literature concerned with the process of change in the teaching and learning process in Technology Education is reviewed. This review is used to establish the factors that influence problem-solving performance with complex ill-defined technological problems. The aim of the chapter is to relate the literature on problem-solving strategies to the literature on problem-solving.
Chapter 4 describes and justifies methods by which the theoretical predictions of Chapters 2 and 3 can be examined. A case study approach is used. A protocol analysis (Ericsson and Simon, 1993) method employed to examine the verbal protocols of problem-solving performance is developed, presented and justified in terms of the theoretical ideas developed in Chapters 2 and 3. The technological problems employed in Studies 1 and 2 are described and justified. The research design employed in both Study 1 and 2 is also presented and justified.

Chapter 5 presents the findings of Study 1. The analysis of the data collected and the interpretation of the findings of Study 1 revealed several outcomes of significance. Firstly, when the participants were given the opportunity to apply problem-solving strategies of their choice, rather than apply known problem-solving strategies all three participants defaulted to a trial-and-error approach. This occurred after the participants had exhausted their knowledge of the problem domain and problem type and were no longer able to draw analogies or transfer knowledge between past problem-solving experiences and a new problem-solving challenge. As a result it is argued that the participants viewed the design challenge as a problem rather than a task. In addition, it was concluded that the participants combined known problem-solving strategies of expert-like problem-solvers with novice-like problem-solving tactics when this phenomena occurred. Further, the trial-and-error approach of the participants resulted in significant cognitive effort being directed towards issues and sub-problems of low priority which in turn produced a number of unsuccessful attempts to solve the design challenge. It is argued that as a result of the trial-and-error approach employed by all the participants that higher numbers of Executive Control and Exploration procedures than Generation procedures were deployed. However, despite the complexities and difficulties of the design challenge and the low number of Generation procedures all participants produced at least one plausible solution for the design brief.

Chapter 6 presents the findings of Study 2. In contrast to Study 1, the participants were not given a choice of problem-solving strategy they could apply to the design challenge of Study 2. In Study 2 the participants were required to apply the ASIT problem-solving strategy to the Brisbane Library design challenge. However, there were several similarities between Study 1 and Study 2. Firstly, like Study 1, Study 2
found that significant cognitive effort was exerted by the participants when solving the design challenge. This was measured by a significant number of non-verbalised intervals such as: ... (pause) and verbalisations such as: sigh, okay and ummm during the study. Secondly, as in Study 1, the participants interpreted the design challenge as a problem rather than a task due to their lack of knowledge and experiences of the problem domain and the problems type. In addition, like Study 1 the participants deployed greater numbers of Executive Control and Exploration procedures than Generation procedures. However, it is argued that ASIT compensated for the comparatively low number of Generation procedures that were deployed by the participants during Study 2, by guiding the problem-solving activities of the participants and controlling their inclination to use a random trial-and-error approach by directing their efforts to produce fruitful results. At the conclusion of Study 2 all of the participants had generated a plausible solution to the design challenge. However, unlike Study 1, two of the participants had produced more than one plausible solution to the design challenge.

Chapter 7 provides a discussion of the theoretical and practical implications of the findings of the two studies. The conclusion is drawn that problem-solving strategies are an important component of the process of solving complex, ill-defined technological problems. The contribution of the thesis to theory and practice is outlined in terms of our understanding of the process of solving complex problems and of the possible implications for complex problem-solving in other areas. Finally, Chapter 7 suggests a number of areas for further research.
CHAPTER 2

PROBLEMS AND PROBLEM-SOLVING

2 INTRODUCTION

This chapter explores the nature of problems, including design-based technological problems, and the way in which people solve them, from a cognitive perspective. The argument is developed that design-based technological problems represent a particular kind of problem that are best solved using particular strategies.

Chapter 2 identifies the need to develop strategies that assist teachers and students solve ill-defined problems. It is argued here that the lack of these problem-solving strategies, and a theoretical basis for their selection and use, is the central gap in knowledge being addressed by this thesis. Pretz, Naples and Sternberg (2003) claim that well-defined problems are sufficiently understood and explained by current theories of problem-solving. However, Pretz et al. also contend that ill-defined problems, which are arguably the most common problems in the real world, are poorly understood by psychologists. As a result Pretz et al. consider that the study of ill-defined problems has been less successful and less fruitful than the study of well-defined problems.

The chapter is structured in the following way. Firstly, the nature of problems, including design based technological problems is examined. Then, the ways in which people recognise, define, represent and solve problems is examined. This is followed by an explanation of the differences in the ways novices and experts undertake problem-solving and finally, strategies that may assist problem-solving are examined.

2.1 What is a Problem?

Newell and Simon (1972) argue that a problem is ... when he [sic] wants something and does not know immediately what series of actions he [sic] can perform to get it (Newell and Simon, 1972, 72). The problems that are encountered can be concrete or abstract, for example, finding food to eat or evidence to prove a hypothesis.
Robertson (2001) presents a similar view to that of Newell and Simon (1972) and claims that: *A problem arises when a living creature has a goal but does not know how this goal is to be reached* (Robertson, 2001, 4). However, Robertson makes a distinction between a problem and task and argues that if the problem-solver knows how to solve the problem it can be considered a task rather than a problem. This thesis is concerned with examining what Robertson defines as problems. That is, it is concerned with complex problems that are often ill-defined.

Newell and Simon maintain that this activity occurs in the problem space which consists of three elements, the problem state, the search space and the goal state. Newell and Simon propose that the problem-solver moves from the problem state where the task and environment are formulated and understood through the search space where the problem-solver applies procedures sometimes called operators and retrieves information from long term memory or from external sources, that will move them forward to the goal state where a solution is reached. In addition to defining the problem space Newell and Simon also define the characteristics of a problem.

### 2.2 Problem Types

Problems come in a variety of types and occur in a variety of contexts. To those with experience it appears obvious what should be done to solve these problems. Thus, Robertson (2001) has identified that the way a problem-solver experiences a problem is as much a function of the problem-solver’s experience and the context of the problem setting as it is of the features of the problem. Given that we experience a diverse range of problems, Robertson has categorised these problems as being:

1. **Knowledge-lean**, where little prior knowledge is needed to solve them
2. **Knowledge-rich**, where a lot of prior knowledge is usually required
3. **Well-defined**, where all of the information needed to solve it is either explicitly given or can be inferred
4. **Ill-defined**, where some aspects of the problem, such as what you are supposed to do, is only vaguely stated
5. **Semantically lean**, where the solver has little experience of the problem type
6. *Semantically rich, where the solver can bring to bear a lot of experience of the problem type*
7. *Insight problems, where the solution is usually preceded with an “Aha!” moment*

(Robertson, 2001, 17)

Robertson’s (2001) definitions build on the earlier work of Newell and Simon (1972) in identifying problem types. However, in addition to identifying a particular problem type and its characteristics, Robertson also recognises the individual problem-solver’s unique contribution to Newell and Simon’s Problem-Solving Space. Yet, Robertson’s research does not identify ... *the phases of the problem-solving process [or] the sequence of which a problem-solver should follow* (Stoyanov and Kirschner, 2007, 50). Nor does the work of Newell and Simon or Robertson’s place any importance on the operational and instrumental problem-solving support, in terms of specific techniques and tools that facilitate problem-solving activities within these phases (Ge and Land, 2004; Stoyanov and Kammers, 2006) (in Stoyanov and Kirschner, 2007, 50). Perhaps this is to be as expected as Stoyanov and Kirschner, (2007) point out *Most of the research on problem-solving has been focused on process-support, identifying the phases of the problem-solving process [or] the sequence a problem-solver should follow* (Stoyanov and Kirschner, 2007, 50). However, Stoyanov and Kirschner argue that although this knowledge is necessary it is not sufficient and a deeper understanding of technological problem-solving is needed.

### 2.3 Characteristics of Ill-defined Problems

Newell and Simon’s work was concerned with the task environment framework for discovering what heuristics people used, and how people used these heuristics to negotiate and search through the problem space. This research direction led Newell and Simon to focus on well-defined puzzles which, according to Hatch, (1988) were well structured and usually have only one correct solution. Payne (2001) maintains that the characteristics of well-defined puzzles are that they have a specific set of operators and a specified problem space. Payne argues that such puzzles include mathematical, chess or computational problems and all of the information to solve the puzzle is either explicitly given or inferred. However, Robertson (2001) contends that most everyday and design-based technological problems are less well-defined and
may be considered ill-defined or ill-structured, thus the need to understand how people solve ill-defined problems.

Robertson (2001) described ill-defined problems as situations *where some aspects of the problem, such as what you are supposed to do, is only vaguely stated* (Robertson, 2011, 17). More recently Stoyanov and Kirschner (2007) argued that in contrast to well-defined problems, ill-defined problems are characterised by several features including: incomplete data or insufficient access to information; alternative and often conflicting approaches to solve the problem; no specific problem-solving strategy; and no defined solution to the problem.

This raises the question as to whether the same cognitive processes are employed to solve both well-defined and ill-defined problems. Stoyanov and Kirschner claim that different intellectual skills are required to solve well-defined and ill-defined problems. In addition, Stoyanov and Kirschner argue that ill-defined problems: *activate specific cognitive processes which may either enable or restrict problem-solving* (Stoyanov and Kirschner, 2007, 50). This then raises the question of how problem-solving is accomplished. This is addressed in the following section.

### 2.4 What is Problem-solving?

Newell and Simon (1972) defined problem-solving as a goal-directed activity. That is, it is an activity where a process of searching for ways to solve the problem results in the achievement of the goal. Since Newell and Simon’s initial research there have been numerous interpretations of the term ‘problem-solving’. Hatch (1988) contends that problem-solving is a situation where a person encounters an obstacle or barrier to reaching their goal and as a result the problem-solver must seek out feasible solution/s to the problem. Similarly, Deluca (1991) defines problem-solving as a process of resolving a known difficulty or difficulties. However, McCormick (1990) (in Boser, 1993) argues that the definition of problem-solving is not straightforward and describes problem-solving as a teaching method that encourages active learning, generic ability to deal with problem situations, a method used in such subjects as mathematics or science, or an empirical investigation.
Despite the various explanations and analyses of problem-solving, Newell and Simon (1972) state that problem-solving occurs within the problem space and the problem space consists of three elements; the problem state, the search space and the goal state. Newell and Simon argue that the problem-solver moves from the problem state where the task and environment are formulated and understood through the search space where the problem-solver applies procedures or operators and recounts information that will move them forward to the goal state where a solution is reached. However, Payne (2001) maintains that people are rarely as organised and patient as Newell and Simon’s model suggests and instead interweave planning and action as necessary, suggesting a more uncertain process than that implied by the Newell and Simon model.

Bransford and Stein (1984) note that in order to be successful when problem-solving humans need to break complex problems into smaller component parts. DeLuca (1992) also found this to be the case and argued that breaking down the complexity of a problem allows people to focus on those tasks that are more likely to lead to a solution. In addition, Payne argues that it is logical to assume that problem-solvers prefer to plan before acting so as to minimise the number of actions required to solve a problem. Green (1989) states that people prefer opportunistic problem-solving strategies rather than any structured strategies such as top-down development. Further, Green claims that opportunistic or trial-and-error approaches lead to the intermingling of high and low level decisions. That is, people prefer not to prioritise or order their decisions or the elements contained within the problem. In addition, Green argues that as a result the problem-solvers’ commitment to possible solution/s varies and the development of a solution in one area may be sacrificed or postponed due to the recognition of potential interactions seen in another area. Green maintains that this strategy causes the problem-solver to frequently evaluate, re-evaluate and modify their solutions to a problem.

### 2.5 Problem-solving Process

Newell and Simon advanced the argument that humans operate as an information processing system (IPS). Newell and Simon describe an IPS as having certain qualities including ... *a memory containing symbol structure, a processor, effectors*
and receptors (Newell and Simon, 1972, 20). Newell and Simon also described the space in which problem-solvers engage in problem-solving activities as being internal. This internal domain is referred to as the problem space. This space, according to Newell and Simon, is an internal representation of the task environment and is ... coupled with a goal, problem, or task ... (Newell and Simon, 1972, 55). In addition, Newell and Simon argue that in this model people solve problems by finding and applying procedures or strategies that will direct them through the search space from the problem state, to reach the goal state (Figure 1).

**Figure 1 Model of a Problem Space**

![Diagram of a Problem Space](Newell and Simon, 1972)

In Newell and Simon’s (1972) problem-solving model (Figure 1) all problems are seen as taking place within the Problem Space. The Problem Space is represented by the bordered area in the above model. In this model the Problem State is viewed as the starting point from which all problem-solving processes commence. As illustrated, the Problem State is represented by a single, defined point, indicating that the starting point of problems can be characterised by one clear descriptor. The Search Space is portrayed as the information space. The information space is the space from which all procedures (described also as operators, actions or strategies) that need to be taken to reach the goal state will be found. The final stage of the model is the Goal State. The Goal State is depicted as a single point indicating that there is a single, correct answer for problems.

Like many subsequent researchers Robertson (2001) appears to adhere to the cognitive problem-solving theory of Newell and Simon (1972) and like them notes that problem-solvers work within the task environment. Robertson claims that in this
environment the problem-solver starts from an initial state, moves on to an intermediate problem state and then to the goal state or solution space. However, Newell and Simon’s (1972) problem space model does not account for problems that may be resolved by a number of solutions or solutions that may point to a number of new directions of investigation to solve the problem. That is, Newell and Simons’ model assumes that there is a correct solution and there are a limited number of ways to reach that solution while Robertson argues that there may be numerous solutions or means by which a solution might be found.

2.6 Cognitive Procedures when Problem-solving

It is argued in this study that by their very nature technological problems are ill-defined, complex and difficult to solve. This study seeks to develop the understanding of technological problem-solving further. In order to achieve this goal this study draws on the theories of metacognition and constructivism.

Gott (1989) refers to metacognition as strategic control knowledge or ... how to decide what to do and when to do it (Gott, 1989, 100). Winn and Snyder (1998) contend that metacognition consists of two basic processes and that these processes occur simultaneously. These processes include monitoring your progress as you learn, and making changes and adapting your strategies in response to what you have learnt (Winn and Snyder, 1998). Ridley, Schutz, Glanz and Weinstein (1992) concluded that these basic processes include a number of metacognitive skill including: ...taking conscious control of learning, planning and selecting strategies, monitoring the progress of learning, correcting errors, analyzing the effectiveness of learning strategies, and changing learning behaviors and strategies when necessary (Ridley, Schutz, Glanz and Weinstein, 1992, 294). Evans (1991) (in Yashin-Shaw, 2003) describes these activities as ‘executive schemas’ and maintains that ... they effect control of the deployment over intellectual resources and the monitoring of progress (Yashin-Shaw, 2003, 173). Gott (1989) theorises that conscious processes that operate under complex conditions are controlled by higher-order procedures. These higher-order procedures are defined in this thesis as Executive Control procedures (Stevenson, 1991). Stevenson and McKavanagh (1992) propose that knowledge such as procedures fits within a hierarchical structure and lower-order thinking is directed
by higher order Executive Control procedures. Yashin-Shaw (2003) argues that second-order thinking includes three categories of thought including generation, exploration and evaluation and that each of these categories are comprised of a set of procedures. The final level in this hierarchical structure is the knowledge base which Yashin-Shaw claims holds a person’s long term memory and that the facts and processes contained within the knowledge base may be operated on by higher levels of thinking.

Kanes (2003) argues that ... many cognitively based theories share the view that the learner actively constructs new knowledge, modifying, extending, replacing and transforming existing knowledge ... (Kanes, 2003, 93) and that this process has come to be known as constructivism. Borich and Tombari (1997) define constructivism as ...an approach to learning in which learners are provided the opportunity to construct their own sense of what is being learned by building internal connection or relationship among the ideas and facts being taught (Borich, Tombari, 1997, 177). A variation on this perspective of learning is that known as social constructivism. Smith and Ragan (1999) state that social constructivism is when ... learning is collaborative with meaning negotiated from multiple perspectives (Smith & Ragan, 1999, 15).

Snowman and Biehler (2000) interprets the social constructivist explanation of learning as meaningful learning occurring when people are taught how to use ... the psychological tools of their culture (like language, mathematics, diagrams, and approaches to problem solving) and are then given the opportunity to use these tools to create a common, or shared, understanding of some phenomenon (Snowman and Biehler, 2000, 295). Darke (1979) considers that this process of problem-solvers learning by constructing their own sense of what is being learned can be explained as the deployment of Exploration and Generation procedures. Darke suggests that Exploration procedures guide the problem-solver to investigate the context, constraints and attributes of a problem while Generation procedures lead the problem-solver to create a solution to a problem or a number of minor solution solutions that may lead to a final solution being realised.

This study draws on the Generation and Exploration theories of Darke, (1979); Finke, Ward and Smith, (1992); Hillier Musgrove and O’Sullivan, (1972), with Generation and Exploration operating under the Executive Control procedures of Stevenson,
It is argued by Darke (1979) that Generation and Exploration procedures compliment one another in the problem-solving process. As a result Finke et al. (1992) combined these procedures to create the Geneplre model. Darke claims that Exploration procedures guide the problem-solver to investigate the context, constraints and attributes of a problem while Generation procedures lead the problem-solver to create a solution to a problem or a number of minor solution solutions that may lead to a final solution being realised.

Foulds (1983) (in Hatch, 1988) argues that algorithms are procedures which guarantee a solution to a problem. Hatch (1988) notes that many problems are well-structured in nature and usually have only one correct answer. Determining the best drill speed for drilling into particular material is one example. Hatch argues that problems such as these can be solved through the application of a simple algorithm. However, Robertson found that due to the unique nature of technological problems they may have more than one correct answer. As a result it is argued that ill-defined technological problems require the problem-solver to consciously employ processes that will lead to the resolution of problems where routine or automated processes and algorithms are inadequate strategies to produce a solution.

Middleton (1998) argues that combining the Generation and Exploration procedures of Darke, (1979); Finke, Ward and Smith, (1992); Hillier, Musgrove and O’Sullivan, (1972), and the Executive Control procedures of Stevenson, (1991), produces a model that allows the researcher to draw conclusions as to the behaviour of problem-solvers when attempting to solve complex ill-defined technological problems. It is this combined model of Middleton that is employed in Studies 1 and 2 to interpret the procedures deployed by the participants when solving ill-defined, complex and difficult to solve technological problems as reported in Chapters 5 and 6.

2.7 Cognitive Artefacts as Problem-solving Strategies

Payne (2001) claims that a crucial determinant of everyday problem-solving success is the presence of factors such as the physical situation and the problem-solver’s ability to manage the relation between planning, perception, and action required to solve the problem. Payne considers that this interaction between the problem-solver
and the physical and social environment is often supported by cognitive artefacts or tools of thought. Payne (2001) argues that these tools of thought may contain a range of artefacts from pencils through to diagrams and graphs or computational systems. Payne refers to these cognitive artefacts as heuristics or strategies and maintains that they may improve the chances of a problem being solved but do not guarantee that it will be successful. However, existing research provides little guidance in terms of the kinds of strategies that might usefully guide technological problem-solving.

To understand the part cognitive artefacts play in the problem-solving process Payne proposes that one approach may be to simply redraw the boundaries of the problem strategy to include the artefacts being used. This approach led Zhang and Norman (1994) to develop a general framework for understanding distributed cognitive tasks. Zhang and Norman suggest that when aspects of a problem can be transferred into the physical environment problem-solving becomes easier.

For example, a hardware store shopper is surprised at the price of the packet of screws they have chosen and guesses that it has been incorrectly labelled. To confirm their theory they want to do a price comparison between the different packets of screws available on the shelf. Payne argues that this comparison can be achieved by using mental division to determine the price per screw and then doing the same calculation on another packet of screws. However, as often is the case no two brands are the same and the screw packets vary in quantity and therefore price. Therefore, instead of using the computational gymnastics of the unit price and quantity comparisons the shopper might search the shelf for packets of screws that contained a similar quantity of screws and directly compare the prices of the two packets. Payne maintains that in this situation the shopper is managing a trade-off between searching for relevant items on the shelf and mental arithmetic. Payne argues that to solve the problem of the screws the shopper is using a heuristic.

Green (1989) contend that artefacts such as the packet of screws or diagrams and drawings can be viewed as ‘information systems’ and as such allow certain information-processing operations to be performed. This can be illustrated through the simple task of recording an appointment in a diary. Payne considers that the diary entry changes the task of remembering the appointment. Payne argues that the action
of naming and writing the appointment in the diary affects the internal memory trace of the appointment and transfers the appointment to an external recording and memory device, allowing its user to retrieve the appointment by reading it at any time. Payne (2001) suggests that this activity in turn leads to the confirmation and reinforcement of previously recorded appointments.

As previously noted, the amount of relevant knowledge a problem-solver possesses, affects the way they solve a problem and the chance that they will be successful in solving it. Research in this area has often been concerned with examining the differences between the ways experts in an area undertake tasks in an area and the ways people new to the area undertake the same tasks. This is often called expert-novice differences and is examined in the following sections.

2.8 Novice versus Expert Problem-solvers

Simon (2001) initially thought that the size of the problem space varied depending on the difficulty of the problem. However, when comparing the problem-solving skills of novice and expert chess players Simon argued that choosing a chess move is very difficult and, as a result, from any typical position there are 1020 or more possible branching paths that might ultimately lead to a won, lost or drawn game. This figure illustrates the possible dimension of the search space when playing chess and based on the assumptions of past hypothesis would indicate a problem of significant difficulty. Yet, Simon believes that humans could search only an insignificant fraction of these paths.

De Groot (1946) (in Simon, 2001, 12121) claims that more skilled players did not search much more extensively than lesser skilled players. In addition, De Groot argues that even grandmasters rarely looked at more than 100 positions before making a move. Simon also found this to be the case and contends that ... domain-specific knowledge ... lay at the basis of expert skills, connecting problem-solving with memory (Simon, 2001, 12121). Simon concludes that the expert problem-solvers are able to recognise familiar patterns that evoke knowledge which in turn guides the problem-solvers search to find strong moves in a limited time.
It is argued that the expert’s search pattern is not significantly larger than the novice ...but along productive instead of unproductive paths (Simon, 2001, 12122) and associated with each search pattern is the ... knowledge of actions that should be explored whenever the pattern is present (Simon, 2001, 12122). Based on the findings of past studies, Payne (2001) argues that expert problem-solvers are more capable problem-solvers than novices because their knowledge of the problem domain allows them to identify and classify problems in terms of the strategies that will be useful to solve them. As a result Payne claims expert problem-solvers are able to reduce the need for extensive searching of the problem space.

Like Simon, Robertson (2001) examined the individual problem-solver’s level of expertise in a particular problem domain. Robertson argues that where a problem-solver can draw on previous experience of the problem type the problem-solver is regarded as Semantically Rich (Robertson, 2001, 17). Robertson contends that when problem-solvers are semantically rich they are able to draw on substantial experience of the problem type. Payne extends this view and suggests that if the problem-solver is semantically rich or has a high level of knowledge and or experience in a particular domain that the problem-solver is considered to be an expert in the specific domain. It is argued, that although a person may have a high level of knowledge and or experience to draw upon to enable them to solve a problem in one particular domain that same person, if asked to solve a problem in a new domain or a new problem type, where they had little or no knowledge, would be viewed as Semantically Lean (Robertson, 2001, 17). In contrast to semantically rich, Robertson states when a problem-solver is semantically lean they have little or not experience of a problem type.

In this instance Payne states that the same problem-solver would therefore be considered a novice due to their lack of knowledge and or experience in the new domain or with the problem type. It is argued here that expert problems solvers are not experts in all situations or domains but rather only in those domains or problem types in which they are semantically rich. Robertson and Payne’s research is useful to this thesis in that it underlines the role of knowledge in solving certain kinds of problems. However, while design-based technological problems do require the
application of existing knowledge, they also require the creation of solutions and solution strategies that have not previously existed. Thus, the gap in our knowledge is of how people solve design-based technological problems and of the strategies they use to accomplish this.

Bransford and Stein (1984) argue that expert problem-solvers usually break down complex problems into simpler component parts which make the problem easier to solve. However, Larkin et al. (1980) (in Payne, 2001) maintain that there are differences in the manner in which novice and expert problem-solvers approach problem-solving. Larkin et al. suggest that novices tend to work backwards from the goal or solution whereas experts tend to work forward from the problem statement toward the problem goal or solution. In addition, Larkin et al. propose that the novice problem-solvers backwards problem-solving strategy enables them to search for knowledge or solutions from previously solved, yet similar problems.

The findings of cognitive research into expert and novice problem-solving by Newell and Simon, Larkin (1972) and De Groot (1946) is supported by the research of Goker (1997), who examined the neurological effects of experience during design based problem-solving tasks. Goker’s findings provide neurological evidence that supports the hypothesis of Simon (2001) and others that novice problem-solvers use different cognitive strategies and areas of the brain to solve problems than do expert problem-solvers.

The first part of Goker’s study was behavioural in nature. The aims of the study were broad and investigated ... how new experiences in a domain are created and learned, how they are indexed and recalled, and how the problems solving experience in a domain affects the problem understanding, the approach used during problem-solving and the created solution space (Goker, 1997, 405).

During Goker’s behavioural experiment, participants were asked to build a virtual machine using a computer and software known as The Incredible Machine (TIM) to solve given design based technological problems. This software ... simulates a design environment in which simple machines can be built using ... 45 provided elements (Goker, 1997, 406). While the participants were completing their design based
technological problems they were asked to think aloud. Their comments, actions, and computer screens were video recorded and later transcribed. In addition, participants were asked to document their solutions and the reasons why they had chosen their particular problem-solving strategies. At the conclusion of the first part of the experiments Goker and a team of investigators analysed the results.

At the completion of this first experiment Goker concluded that the experience a person brought to the test was a significant factor in the person’s comprehension of the problem. Goker argues that if the problem-solver ... had experience with a similar assignment, [and was therefore an experienced problem-solver in this domain] the test person solved it directly and perceived [it] as a task (Goker, 1997, 408). On the other hand, Goker claims that: If no experience was available [and problem-solver was a novice in this domain], the assignment posed a problem and deductive or trial-and-error approaches were applied (Goker, 1997, 409).

The second part of Goker’s study explored the neurological brain activities that are activated when experienced versus novice problems solvers are presented with a computer simulated problem. Goker qualifies this research by stating that because of the small sample of participants the experiments that were conducted can only be considered as a case study. However, the primary aim of this part of the Goker’s study was to identify the different regions of the brain that are activated when novices and experts solve problems.

The second part of the experiment was set up in a similar way as the first. Participants were asked to solve a number of problems, their verbalisations and the computer screens they were using were video recorded. In addition, the participants were connected to an Electroencephalogram (EEG). An EEG is a medical procedure used to measure the electrical activity of the brain. This electrical activity is then displayed and recorded through the use of an EEG machine that uses a series of electrodes that are applied to the scalp of the patient or participant. The results of these examinations were recorded and later interpreted by Goker and the research team using various software applications. Via this interpretation Goker was able to document the regions of the brain that showed particular activity when the participants were engaged in various aspects of the problem-solving.
Goker (1997) argued on the basis of the study that although the *functions of the regions of the human brain are not fully understood and the mapping of tasks has not necessarily been decided upon* (Goker, 1997, 410) that certain assumptions regarding the functions of the brain can be made based on prior neurological research. The assumptions are illustrated in Figure 2 below.

**Figure 2 Assumptions Regarding the Function of Regions of the Brain**

![Figure 2 Assumptions Regarding the Function of Regions of the Brain](image)

(Goker, 1997, 412)

Goker (1997) argued that the assumptions made regarding the regions of the brain and their activity can be explained as follows:

*... activity in the frontal regions is a sign of planning, reasoning and decision making. The left hemisphere specialises in the processing of abstract concepts and language, and contains our verbal memory. The right hemisphere is specialised in processing visual information and contains our visual memory.*

(Goker, 1997, 410)

As a result of the second part of the study Goker (1997) came to a number of conclusions regarding the regions of the brain that are actively stimulated and the length of time each area is active when either a novice or expert is observed solving problems. In summary the EEG experiments indicate that novices and experts use the
same regions of the brain for problem-solving. However, the length of time each region of the brain is actively engaged in the problem-solving process varies depending on the problems solver’s experience and knowledge in a particular problem domain.

Goker’s results indicate that novices show longer brain activity in the frontal regions where planning, reasoning and decision making activities are performed, whereas expert problem-solvers have longer activity in the parietal region of the brain. Goker interprets this finding as indicating that novice problems solvers spend more time looking for past, but not necessarily relevant, solutions that might provide some guidance as to how to solve the problem rather than applying proven prior knowledge and schemas as demonstrated by expert problem-solvers. The conclusion to be drawn from Goker’s study is that domain knowledge is important to the successful resolution of problems, but that we do not yet know what domain knowledge (of content and procedures) is required to successfully solve design-based technological problems.

The way in which people approach problem-solving activity is influenced by knowledge of the domain, as noted above. However, previous knowledge and expertise may also prejudice the problem-solver’s efforts to solve technological problems. Duncker (1945) argued that functional fixedness is a cognitive bias that impairs the problem-solver’s ability to use an object in a new context or for a new purpose. Duncker notes that this occurs due to the problem-solver’s previous experience of the object. In addition, Duncker contends that functional fixedness is not limited to physical objects but can also occur with mental objects or concepts.

Similar to Duncker’s theory of functional fixedness is Luchins and Luchins (1959) theory of rigidity of behaviour which is also known as mechanisation bias. Luchins et al. suggest that this phenomenon occurs at a time when a problem-solver is presented with a problem or situation that is familiar to them. As a result of this apparent familiarity Luchins et al. claim that problem-solvers use problem-solving strategies that they had previously used to solve problems and exclude other problem-solving strategies that may be quicker or more efficient.
Luchins et al. (1959) state that problem-solvers unwillingness or inability to modify their problem-solving behaviour results in a mechanised problem-solving approach. As a result Luchins et al. claim that rigidity of behaviour indicates the presence of the Einstellung effect. Luchins and Luchins argue that the Einstellung effect is where the problem-solver employs the most efficient behavior or strategy possible to solve a problem. However, Luchins et al. note that although this solution may be the most efficient, it may not necessarily be the most appropriate solution to the problem.

It is also the case that problem-solving activity is influenced by the personal attributes of the problem-solver. These can include such factors as personality and the more difficult to define concept of problem-solving style. Personal and technological problem-solving styles are examined in the following sections.

2.9 Personal and Technological Problem-solving Styles

Wu, Custer, and Dyrenfurth (1996) argued that people face different types of problems in their everyday lives yet many of these problems are not technological in nature. The focus of the Wu et al. study was to compare the personal everyday and technological problem-solving styles of a group of university students. Problem-solving style as defined by Wu, et al. is ... a tendency to respond in a certain way while addressing problems and not as the steps employed in actually solving the problem (Wu et al., 1996, 55).

To measure problem-solving styles Wu et al., turned to the Problem Solving Inventory (PSI-PSYCH) developed by Heppner (1988) (in Wu et al., 1996). Heppner defined problem-solving styles in terms of three distinct constructs and measured these constructs by way of the Problem Solving Inventory (PSI-PSYCH) (Heppner, 1988). These constructs included ... problem-solving confidence, approach/avoidance style, and personal control (Heppner, 1988) (in Wu et al., 1996, 62). Heppner defines these constructs as:

*Problem solving Confidence* [...] *self-assurance while engaging in problem-solving activities (p. 1)*; *Approach/Avoidance* [...] *a general tendency of individuals to approach or avoid problem-solving activities (p. 2)*; and *Personal Control* [...] *the extent to which individuals believe*
that they are in control of their emotions and behaviour while solving problems ...  

(Heppner, 1988, in Wu et al., 1996, 57)

Wu et al. (1996) adapted Heppner’s, (1988) PSI-PSYCH instrument to measure technological problem-solving style (PSI-TECH). Wu et al. argue that the technological version of the PSI-TECH instrument examines perceived efficacy with technological problems.

The student groups selected for the study ranged from students who were highly inclined to be interested and involved in Technology to those who with a minimal inclination to be interested and involved in Technology. This study group included undergraduate university students majoring in the Technology, Engineering, and Humanities disciplines. The purpose of the Wu et al. study was to determine if ...technological problem-solving is similar to, or different from, personal [everyday] forms of problem-solving (Wu et al., 1996, 56) and sought to answer three questions:

1. Do distinctly different types of university students exhibit significant differences in their styles of personal and technological problem-solving?

2. Do students from different academic majors and with different demographic characteristics exhibit significant differences in personal and technological problem-solving styles?

3. Can differences in technological and personal problem-solving be inferred on the basis of problem-solving style?  

(Wu et al., 1996, 57)

Wu et al. compared the academic areas of the participating groups and argue that Technology-related programs exist to develop an understanding of, and capability to use, key aspects of industry and technology … [and] ... draws from both engineering and technology theory (Wu et al., 1996, 58). However, Wu et al. also note that engineering programs also have a technological emphasis; however, they tend to be more theoretical and less hands on. In contrast Wu et al. contend that humanities students receive significant portions of their training in general courses as well as a concentration in a given liberal arts discipline. In addition, Wu et al., state that the careers of humanities students do not tend to involve technological or engineering
concepts but rather focus on abstract liberal arts content (Wu et al., 1996, 58). The interrelationships between these three different disciplines is conceptualised by Wu et al. as a function of technological and theoretical dimensions. Figure 3 below illustrates the relationship of each of the study groups to Technology.

**Figure 3 Envisioned Relationship Among Three Different Academic Areas**

At the conclusion of the study, Wu et al. (1996) argue that: *No significant differences were detected among the three majors on the overall personal [everyday] problem-solving scale* (Wu et al., 1996, 65). However, differences were noted *between personal [everyday] problem-solving and technological problem-solving scores within the individual disciplines* (Wu et al., 1996, 65). According to Wu et al. these differences were found to be significant for Humanities students and Technology students, but not for engineering students. On the Technology problem-solving scale the Humanities students had the highest score (least positive) while the Engineering students had the second highest score and the Technology students had the lowest score (most positive). Overall the Technology students were found to have the lowest scores (most positive) in technological problem-solving and medium scores in personal problem-solving.

In conclusion, Wu et al. suggest that *personal and technological problem-solving styles may well be separate and distinct* (Wu et al. 1996, 69) and assuming that there are generalised problem-solving skills that can be applied to solve such diverse activities as *marital problems and trouble-shooting electronic circuits* (Wu et al.
1996, 69) may be inappropriate. As a result Wu et al. state that ...different types of problem situations (e.g., personal or technological) require different kinds and levels of knowledge and capability... including problem-solving skills (Wu et al. 1996, 69).

Eisentraut’s (1999) study: Styles of problem-solving and their influence on the design process, revealed results similar to that of Wu et al. Eisentraut defined problem-solving style as an ...individual’s preferred way of action regulation in dealing with complex problems (Eisentraut, 1999, 432). Although Eisentraut’s study was not as broad as the study by Wu et al., it was comparable in that it investigated a similar tertiary student group, that of engineering students and their problem-solving styles.

Eisentraut’s study investigated the design processes of student engineers in three controlled experiments. The students worked on ... two simulated complex problems ('Machine' and 'Fire'), and the third one was an adaptive design problem ('Writing table') (Eisentraut, 1999, 432). The experiment was carried out in a controlled laboratory situation (Eisentraut) and the participants were working in a conventional design workspace with sketch paper and a drawing board (Eisentraut). During the data collection of Eisentraut’s study, participants were asked to think aloud. That is, they were asked to express all their thoughts verbally while designing and the entire process was recorded by means of a video camera.

Eisentraut first compared the students’ procedures or strategies in the three problem situations. Eisentraut concluded that the ways in which individuals worked on the different problems were quite similar. For example, similarities mean the amount of information gathering or the speed of action (Eisentraut). Eisentraut concluded from this observation that:

... a person’s proceeding [or strategy] in complex problem situations, significantly, depends on his or her style of problem-solving regardless of whether the problem situation is a design problem, a computer simulated fire fight or the operation of a computer simulated plant.

(Eisentraut, 1999, 433–4)

However, Eisentraut (1999) argues that the problem-solvers success does not only depend on the individual’s style but rather on whether or not the ... style of problem-
solving meets the demands of the situation (Eisentraut, 1999, 433). Eisentraut concluded that ... diagnosing and training individual problem-solving behaviour may make an essential contribution [towards optimising] individual design processes and therefore should be a part of design education as well as of further vocational training (Eisentraut, 1999, 431). This finding strengthens the work of Wu et al. (1996) and the argument advanced in this thesis that specific design strategies are important for solving design based technological problems. The contribution of Wu et al. and Eisentraut’s studies to this thesis are in identifying personal style as a variable that needs to be accounted for when identifying strategies for solving design based technological problems.

2.10 Problem-solving Model

Sivaloganathan (2000) argues that the conventional model for solving technological problems is one that directs the problem-solver in a linear fashion from understanding the design brief through to resolving the problem and then improving the final design, as seen in Figure 4:
Figure 4 Conventional Model for Solving Design Problems

(Sivaloganathan, 2000, 63)

Figure 4 illustrates a conventional design based problem-solving model as suggested by Sivaloganathan (2000). However, observations in school practice by the thesis author find that a model that applies greater emphasis on the making and doing sections of the design challenge and less on the research and idea generation elements is more commonly used by teachers and students, see Figure 5:
It is argued that these technological problem-solving models have limitations as they do not suggest the means by which the problem-solver is to resolve a specific problem or task within the design challenge. It is argued that structured problem-solving strategies may have a role to play in guiding the problem-solver towards developing a plausible solution to a technological problem. The following section identifies two problem-solving systems, known by their acronyms of TRIZ and ASIT, as potential structured problem-solving strategies and examines their appropriateness for identifying how to solve technological problems once the nature of a problem is identified. Their ability to address the limitations of the conventional technology problem-solving models is discussed in detail in 3.10 and 3.11.

2.10.1 TRIZ
TRIZ is an acronym for the Russian words Teoriya Resheniya Izobretatelskikh Zadatch which in English means the Theory of the Solution of Inventive Problems (Altshuller, 1990). The TRIZ problem-solving process was developed by Altshuller during the 1950’s. During this period Altshuller identified the underlying patterns by which people, mostly engineers in the former Soviet Union, solved technological problems and produced inventions to solve these problems. These patterns of inventions formed the basis of TRIZ. According to the principles of TRIZ an invention is an idea that does not succumb to contradiction but rather progresses contradictions in a positive direction.
During Altshuller’s (1990) evaluation of inventions in the USSR Patents Office, Altshuller discovered that the patents represented technical solutions that varied greatly in their degree of inventiveness. Altshuller also observed that inventive problems involved overcoming technical contradictions. The result of contradictions in design is when the improvement of one feature causes the degradation of another. For example, reducing the weight of a structural beam generally also reduces the strength of the beam. Rawlinson (2001) claims that problem-solving strategies such as TRIZ are structured thinking processes.

Altshuller also developed a list of 39 engineering parameters such as force, speed and strength and 40 operators that he named Inventive Principles (Altshuller, 1990) for eliminating technical contradictions. The engineering parameters were assembled in a table of 39 rows of Improving Features and 39 columns of Worsening Features. This table is referred to as the Classical TRIZ Matrix. Contained in each of the intersecting cells is the list of Inventive Principles that can be applied to the technical contradictions. A detailed explanation of the Classical TRIZ Matrix can be found in 3.10.

Mann, Dewaulf, Zlotin and Zusman (2003) argue that there is a likelihood of between 10% – 50% that a solution to a modern-day problem could be derived from the Classical Contradiction Matrix (Altshuller). The low rate of success has, however, led a small group of researchers to investigate patents granted since 1985 and the problems and solutions contained within them (Mann et al., 2003). This has seen the development and enrichment of the 39 parameters of the original Classical Contradiction Matrix (Altshuller) resulting in a new and re-sequenced Contradiction Matrix (Mann et al.) of 40 eight parameters. However, the need to continually develop and add further parameters to the matrix has increased the complexity of the TRIZ problem-solving strategy even further. This has led to development of systems based on TRIZ that are seen to be simpler and more suitable for a wider range of problem types. ASIT is one such system and it is examined in the next section.
2.10.2 The ASIT Systematic Approach to Solving Design Problems

A review and analysis of TRIZ was undertaken as part of this thesis. It was found that while TRIZ was useful when applied by TRIZ experts when solving engineering problems, it was less useful in solving a broader range of ill-defined technological problems, of the kind encountered by pre-service Technology teachers and by Technology Education students in schools. As a result the researcher trialled a modified set of strategies that are known as the ASIT problem-solving process. ASIT is an acronym for the Advanced Systematic of Inventive Thinking (Horowitz, 2001). Although ASIT is derived from the original TRIZ problem-solving system it was found to be significantly simpler to understand and apply to ill-defined technological problems. In effect, ASIT seeks to solve ill-defined technological problems by directing the problem-solver through a number of simple steps. These steps include: defining the Problem World, identify the aggravating factors and if any aggravating factors or elements are found, turn them into beneficial or neutral ones, and finally, searching for a solution that does not add any new type of objects to the Problem World. In addition, ASIT seeks to prevent or limit the tendency of the problem-solver to be hindered by functional fixedness. ASIT is discussed in detail in 3.11.

Larkin, McDermott, Simon, and Simon (1980) (in Payne, 2001) claimed that experts tend to work forward from the problem statement toward the problem goal or solution and not backwards from the goal as novices prefer. Therefore, it is argued that the favoured problem-solving strategy of experts is in contrast to the strategies employed in problem-solving processes such as TRIZ and ASIT (examined in 3.10 and 3.11) as these processes direct the problem-solver to work backwards from the goal or solution. This is interpreted as indicating that problem-solving strategies such as TRIZ and ASIT are structured in such a way as to assist novice problem-solvers with the use of specific search strategies to solve problems rather than expert problem-solvers as they appear counterintuitive for them.

2.11 Conclusion

Chapter 2 explores what defines a problem, the nature of problems including everyday problems and complex, design based technological problems and the manner in which problem-solvers solve these problems. It is argued that complex technological
problems represent a unique kind of problem that is best solved using particular strategies. Chapter 2 argues that there is a lack of appropriate problem-solving strategies that are based on solid theoretical foundations available to assist teachers and students.

Newell and Simon (1972) believed that a problem is a situation where a need arises but the actions required by the problem-solver to solve the problem are not known. In addition, Newell and Simon found that there are three elements to problem-solving that the problem-solver moves through in order to reach a solution.

Similarly Robertson (2001) interprets a problem as a goal that is not known how to be reached, whereas a task is when the problem-solver knows how a solution can be made. Further, Robertson claims that a problem-solver’s prior knowledge and experiences affect how a problem-solver experiences a problem. Robertson categorises problems into seven types due to the variety of characteristics and settings problems can have. However, most everyday and design based technological problems are less well-defined, thus the need to understand how people solve problems and what problem-solving strategies they use. This thesis adopts Robertson’s definition of a problem, i.e. complex problems that are often ill-defined.

There have been numerous interpretations of the term problem-solving; however, this thesis examines Bransford and Stein’s (1984), Deluca’s (1992), Payne’s (2001) and Green’s (1989) explanations. The interpretations of these researchers collectively address complex technological problems by breaking them down into their component parts, focusing the attention of problem-solvers on relevant tasks, encouraging planning before acting to reduce the number of actions required and adopting a trial-and-error or opportunistic approach in order to resolve a complex technological problem. No assumptions are made in this thesis as to which interpretation or model problem-solvers adopt, but rather seeks to identify which of these interpretations or models problem-solvers prefer when solving technological problems.

Newell and Simon argue that the problem-solving process has three clearly defined states which result in a single, correct answer, whereas Robertson’s view refers to
problem-solving as either finding the final solution or answer, or the means of finding the solution procedure.

Payne (2001) argues that problem-solving involves the interaction of cognitive artefacts or heuristics. Green (1989) contends that the artefacts can be viewed as an information system. However, Payne notes that although problem-solving strategies or heuristics can improve the chances of solving a problem, they do not guarantee that a successful resolution of the problem will be reached.

The depth of prior knowledge and experience a problem-solver possesses also affects their chances of success when problem-solving. This is evident in Simon’s (2001) study which found that an expert’s prior knowledge guides their search along productive paths, thereby eliminating the need for extensive searching. However, Duncker (1945) and Luchins et al. (1959) claim that problem-solvers are affected by the influence of previous experiences and may suffer from the Einstellung effect where problem-solvers automatically choose the quickest and shorted route to solve a problem without consideration of its appropriateness for the situation.

Gott (1989) argues that metacognition is the cognitive process of deciding what to do and when to do it. Ridley, Schutz, Glanz and Weinstein (1992) state that there are a number of metacognitive skills required for this process to take place. Evans (1991) (in Yashin-Shaw, 2003) describes these activities as ‘executive schemas’. Gott suggests that they are controlled by higher order procedures. These procedures are defined as Executive Control procedures by Stevenson (1991).

Kanes (2003) maintains that learners actively construct new knowledge, modify, extend, replace and transform existing knowledge and that this process has come to be known as constructivism. Darke (1979) argues that this process can be explained as Exploration and Generation procedures. Darke and Finke, Ward and Smith (1992) theorise that the cognitive processes of the problem-solver can be explored through characterising the procedures they deploy whilst engaged in problem-solving activities. As a result Finke et al. developed the Geneploroe model which combines the Generation and Exploration procedures. Finke et al. surmised that these procedures are deployed when problem-solvers are exploring the attributes of a problem and
generating possible solutions to resolve the solution. However, Stevenson argued that both of these cognitive procedures operate under the guidance of Executive Control procedures which determine what is to be done and when it is to be done. Technological problems require the application of existing knowledge and also the creation of solutions and solution strategies that have not previously existed. As problem-solving strategies, TRIZ (Altshuller, 1990) and ASIT (Horowitz, 2001) are structured to guide the problem-solver to work backwards from the goal, as is the tendency of novice problem-solvers, rather than forwards to the solution as most experts prefer.

Goker’s (1997) research found that although novice and expert problem-solvers use the same region of the brain for problem-solving, the length of time that each region is actively engaged varies between them. Goker’s results further demonstrate that the areas of the brain showing longer activity in novice problem-solvers suggesting that they spend more time looking for past solutions than experts.

Wu et al. believe that specific problems solving strategies are needed for solving complex technological problems. Each problem presents with a unique array of tasks requiring a different mix of skills, knowledge, experience and personal styles. In addition, Eisentraut (1999) suggests that the style of the problem-solver must meet the demands of the problem. However, Eisentraut argues that as there is such a diverse range of problems and situations different personal styles and levels of knowledge are required to solve each problem successfully.

TRIZ was developed in the 1950’s as a means of understanding how people, mainly engineers, solve technological problems and to identify the inventions they produce in order to solve these problems. Initially, the TRIZ strategy consisted of five levels of inventiveness, eight Laws of Development of Engineering Systems and a Classical Contradiction Matrix (Altshuller). However, over the period since the development of Classical TRIZ (Altshuller) its solution success rate has been low. As a result the Classical Contradiction Matrix has since been expanded upon and the need to continually develop further parameters as modern day problems evolve further increases the strategy’s complexity.
It was found that although TRIZ is a valuable tool for experts in the engineering field, it was not as effective in solving the often ill-defined design based technological problems found in the school classroom and presented to pre-service Technology teachers. As a result, this thesis investigates the appropriateness of the simpler ASIT strategy as an effective problem-solving strategy for solving design based technological problems in the Technology classroom.

Chapter 3 explores existing research and pedagogical approaches to technological problem-solving and argues that research using ASIT as a pedagogical tool represents an approach through which this important gap in knowledge may be addressed.
CHAPTER 3

PEDAGOGY FOR TECHNOLOGICAL PROBLEM-SOLVING

3 INTRODUCTION

Chapter 2 examined the nature of problems and the ways in which people solve them. Chapter 2 also examines the importance of the ability to solve the kinds of complex, ill-defined technological problems that are a feature of contemporary life. The recognition of this change in the nature of the 21st century world and the need for education to respond to it has been incorporated into many Technology Education curriculum documents around the world (See Curriculum Corporation, 1994: International Technology Education Association, 2000 for examples). This chapter explores the implications of this change for Technology teacher education programs, and the impact of the teaching and learning process in Technology Education classrooms in schools.

The Australian Technology Key Learning Area (KLA) represents a new approach to teaching and learning, with problem-solving being the basis for pedagogy. That is, problem-solving is the basis for the activity students engage in and the activity that teachers should facilitate and have the skills to be able to facilitate. Problem-solving represents a significant shift for teacher education students.

This chapter is structured in the following way. Initially, four factors that are seen to influence the change in pedagogy to a problem-solving approach in Technology are examined: (a) the difficulties in moving from a directed approach to teaching to a design based approach, (b) the role of the design brief, (c) the nature of the learning environment and (d) the role of assessment. Then, specific strategies for facilitating technological problem-solving are examined. These include strategies drawn from psychology and engineering strategies known by their acronyms of TRIZ and ASIT. Finally, conclusions are drawn as to the kinds of gaps the examination of literature reveal and the implications for the kind of empirical study undertaken and described in Chapter 4 and reported in Chapters 5 and 6.
3.1 Teaching Methods

In examining the features of the teaching and learning methods that are generally referred to as directed learning, Schwartz and Saddler (2003) argued that an Industrial Arts instructional methodology does not allow students to choose goals or strategies to reach those goals as the teacher makes these decisions and choices for the student. The position of Schwartz and Saddler supports the work of Wu et al. (1996).

Wu et al. state that specific problem-solving strategies are needed for Technology Education as opposed to relying on generic problem-solving strategies that are used to solve all problems, including life’s problems and technological problems. Wu et al. also suggest that Technology teachers need to introduce these technological problem-solving strategies as early as possible in the students academic career … to encourage children to actively explore and interact with both personal and technological problems when they are inherently curious about and actively engaged with their world and while their problem-solving styles are still in the developmental process (Wu et al., 1996, 69).

In addition, Schwartz and Saddler theorise that when students of a traditional non-design based class were asked what the goal for the class was they stated that the goals was to follow the teacher’s instruction. However, Schwartz and Saddler contend that the clearly stated goals of design-based activities offer students an opportunity to remove teachers from the feedback role and allow the student greater decision-making autonomy. Thus, while the teacher may choose the goals for the design-based activity the intention was that students chose the strategies for achieving the goal.

The clearly stated goal of the design brief employed in the Technology class removes any doubt about what it is that students need to do and offers students the freedom to engage the strategies that they feel are needed to achieve the design goal. Schwartz and Saddler (1996) argue that if the Technology class is Properly managed, the design-based activity invites students to use strategies they think useful, and if teachers exploit the iterative possibilities of such activities, then students can respond to the feedback that is generated from the strategies they choose (Saddler, 1996, 4). Schwartz and Saddler highlight the tensions and possible confusions between the
intention to have students solve problems in creative ways and the nature of possible teacher interaction or facilitation of that creative problem-solving.

3.2 Implementing Change
The Technology teacher profile in Australia is similar to that of the teaching profession in general in that it is an ageing workforce (Australian Bureau of Statistics, 2011). This determines that while new design-based Technology curricula have been implemented over the last 15 years (QSA, 2003), many teachers have initial teacher training in traditional directed teaching methods (Middleton, 2003). As a result, these teachers can experience difficulties in creating a suitable environment for problem-solving (Middleton). The following section explores these issues and on the basis of the exploration argues that Technology teachers with traditional teaching approaches have difficulty in implementing problem-solving approaches to Technology Education. The difficulties occur in terms of content, process, establishing appropriate learning environments and assessment procedures.

3.3 Confusing Content with Process
One issue that has been addressed in the research literature is that of content versus process. That is, whether a contemporary Technology Education program should concentrate on incorporating new technological content or focus on developing technological problem-solving skills. Weber and Custer (2005) surmise that all students need to acquire the necessary skills to become critical consumers and assess the technologies they use. Weber and Custer claim that critical consumers are able to able to make informed decisions about the technological world. This conclusion by Weber and Custer is in response to the argument by prominent economic spokespersons in the United States of America who see these new abilities as important for economic growth (Weber and Custer). Thus there is the imperative to develop the critical thinking skills often associated with design based problem-solving.

Others argue that the essential process skills advocated by Weber and Custer are lost in the desire to be seen to be modern. Zuga and Bjorkquist (1989) state that in an
effort to make school Technology more appealing and seen as ‘high technology’, educators have been seduced by the appeal of the latest and greatest hardware rather than focusing on courses which may provide ... opportunities for students to be creative, improve their problem-solving abilities, become critical consumers, and develop technological literacy (Zuga and Bjorkquist, 1989, 1).

Lewis (1999) supports the position of Zuga and Bjorkquist (1989) and notes that Technology Education is not the technology of Silicon Valley and therefore does not have to mirror the current technological devices. Further, Lewis states that Technology in schools should be concerned with engaging, exciting and inspiring students rather than being preoccupied with the latest equipment and software. Thus Zuga and Bjorkquist and Lewis have highlighted the limitations of only focussing on new technological devices which, if not used in appropriate learning activities, may not challenge students to use their creativity and in many cases require low level thinking strategies from students.

Zuga and Bjorkquist claim that high technology courses appeal to those educators who are fascinated by the … mechanization of modern life and they give the outward appearance of being advanced subject matter within the schools (Zuga and Bjorkquist, 1989, 1). This focus on high technology leads to an attitude of ‘Look at Technology’ rather than the purpose of Technology Education which was conceived as a … general education and dedicated to liberating the minds of its learners (Zuga and Bjorkquist, 1989, 1). In this environment of high technology it is not uncommon for students to learn to … manipulate robots in exercises that are tightly described by the teacher within timelines controlled by the school schedule, or to find answers to problems that no one really cares about (Zuga and Bjorkquist, 1989, 1). That is, the exercises may be appear to be high technology but are not seen by students as meaningful and that require only low level thinking skills. Paradoxically, teachers who are instructing students in what might appear to be more traditional workshop technologies may also be teaching students how to … solve problems that they have identified, how to develop methods for study, and how to evaluate alternative outcomes in systematic fashion (Zuga and Bjorkquist, 1989, 1).
Zuga and Bjorkquist (1989) argue that there … *are opportunities in both subjects to prepare students for the future as well as to deny them learning experiences that will engage their powers to do such things as identify and solve problems* (Zuga and Bjorkquist, 1989, 1). However, it is the activities of the latter example that are … *developing technologically literate people* (Zuga and Bjorkquist, 1989, 1). In drawing conclusions about content and process in Technology Education, Zuga and Bjorkquist (1989) suggest that it is the manner in which a course is organised, delivered and taught that … *demonstrates a type of educational activity that attempts to prepare students to be independent thinkers and problem-solvers* (Zuga and Bjorkquist, 1989, 2).

Zuga and Bjorkquist argue also that the apparent fascination with the latest and greatest technology does not necessarily lead to the best instruction in Technology Education and in many cases the may be used to camouflage inferior teaching. In addition, Zuga and Bjorkquist believe that the continued focus on the technological devices in the classroom has resulted in insufficient attention being given to the methodology of instruction. Thus, Zuga and Bjorkquist surmise that it is the kinds of activities provided for students to engage with and the nature of that engagement, including the role of the teacher that is of primary concern rather than the content of the course which may be a secondary issue. However, the nature of student engagement and the kinds of skills that a teacher needs to bring to the classroom, represent gaps in the literature.

One issue that represents a tangible difference between directed teaching approaches and approaches based on creative problem-solving is the description of the learning task. This is addressed in the following section.

### 3.4 The Role of the Design Brief

In a Technology approach the description of the learning task is generally presented in the form of a design brief. The design brief contains the design challenge or task that students are to respond to. In this thesis the term ‘design brief’ is adopted to describe the document in which the design challenge is described. Design briefs can vary in terms of their structure, format and the degree of creative freedom given to the problem-solver. They are sometimes defined in terms of a continuum that has at one
end the open design brief and at the other the closed design brief. Barlex, Budgett-Meakin, Compton and Everett (1995) argue that the open design brief affords the designer a large degree of freedom to experiment with designs and solution to a problem. The assumption with an open design brief is that the student will have greater flexibility to be more creative and innovative. In contrast a closed design brief restricts the degree of freedom of choice to which problem-solvers can experiment with designs and solution to a problem and usually results in one solution. The design brief may specify the materials or processes the problem-solver can use and limit opportunities to explore alternatives.

Barlex et al. argue that the open design brief contextualises the need or problem; though, it does not define the solution, for example: Your design challenge is to find a way to keep drawing equipment tidy on your desk at home. In contrast, the closed design brief quite specifically defines what the student is to produce in response to the design brief and often includes function and limitations. For example, a closed design brief might be; Your challenge is to design and make a pencil-case. Such a design brief is not intrinsically closed and a number of solutions may be presented for this design brief. However, observations of school practice by the thesis author suggest that the type of product made to answer the closed design brief is limited, thereby restricting students’ creative freedom and innovativeness.

Horowitz (2001) suggests, however, that a closed design brief may encourage technological problem-solvers to create more inventive solutions as it focuses the students on the immediate problem and restricts the introduction of new elements into the solution. (Strategies for solving problems are examined in 3.7, including methods that appear to use a closed approach as a means of increasing creativity.) Horowitz (2001a) notes that in order to produce creative solutions to technological problems, problem-solvers need strategies that will restrain their tendency to complicate the problem by introducing new elements into a problem. One conclusion to be drawn from the limited research on the nature of design briefs and their influence on the problem-solving process and creativity is that this represents an under-researched area and thus a gap in the literature.
Another aspect of Technology Education that appears to be important is the nature of the learning environment that learners experience. Research on this topic is addressed in the following sections.

### 3.5 Learning Environments

Sidorchuk and Khomenko (2006) argue that the classroom learning environment plays a large part in the learning successes of students and the Technology Education classroom is no exception. However, the Technology classroom environment is somewhat unique in the school, as Lewis (1999) notes below:

> Come Monday morning in technology [sic] education classrooms, teachers and their students meet once more to enact the subject. The better teachers make arrangements to allow for the varying interests and abilities of their charges. And once classes got going, the onlooker sees a hive of activity. In this milieu we find the essence of the subject. Content and processes are important of course, but they are not kept in separate compartments. Rather, these teachers see the subject as a whole. There is fluidity and curricular decisions will be made on the spot (see Holt, 1996 for how we might view this dynamic). As teachers and their students interact, there is dialogue, give and take between them. In the midst of these dialogues and interactions, the curriculum comes to life. Machines are turned on and materials cut to length. Holes are drilled. Jigs and fixtures are proven out. Teachers are on constant alert for safety infringements. Students are free to talk, as in few other classes. Computers are turned on. Drawings are pored over.

(Lewis, 1999, 56)

Thus Lewis makes the case that Technology classrooms provide a particular kind of learning environment. Lewis does not specifically talk about facilitating a problem-solving design approach, though, he does allude to a classroom where students are actively engaged in constructing their own learning. Sidorchuk and Khomenko argue that a social atmosphere provides a ‘safe culture of learning’ and encourages students to listen to each other, to be happy for each other’s success and to respect the opinions of their colleagues. It is claimed by Sidorchuk and Khomenko that as a result of a safe learning environment, students feel able to take creative risks and try new tasks and ideas that will develop their skills and knowledge further.

It is argued here that this environment, in turn, may allow students to be more spontaneous and creative with their designs and problem-solving solutions if they feel
intellectually comfortable and emotionally safe in their classroom surroundings. This culture of learning and the learner-centred approach is encouraged in curriculum documents such as the Years 1 to 10 Queensland Technology Syllabus, where it indicates the learning environment should be one that ... provides opportunities for students to practice critical and creative thinking, problem-solving and decision making when meeting design challenges (QSA, 2003, 10). One feature of the teaching and learning process that is known to influence the nature of learning is the ways by which learning is assessed and this is addressed in the following sections.

3.6 Assessment
Assessment of directed learning in the industrial/manual arts classroom has often been seen as a precise and unproblematic process. Teachers assess the degree to which a pre-specified product has been produced by each student. Degrees of success are measured by the closeness to the specified plans each student’s product is said to have achieved. This closeness to the specified plans is assumed to have a one-to-one correspondence with the amount of learning that each student has achieved.

The learning outcomes in a design based Technology classroom are regarded as requiring different assessment approaches than those employed in directed learning classrooms. It also appears to be the case that while there is a general understanding that assessment is one of the drivers of both student learning activity and direction, there is limited research to inform practice. In a four-country study, Kimbell (1997) found that when assessing design based learning, a holistic approach to assessing design output was necessary. That is, Kimbell found that the atomistic approach to assessment is often done in the belief that such an approach will be more objective and reliable, in fact reduced rather than enhanced the reliability of assessment.

A more recent problem in assessing student performance in Technology has been identified by Kimbell (2004). The issue is the tendency for student work to become less creative and more recipe-like in an apparent attempt to satisfy perceived external assessment requirements. The issue was reported in the Kimbell (2004) paper: Assessment in design and technology education for the department of education and skills. Kimbell, Miller, Bain, Wright, Wheeler, and Stables, (2004) performed the
study: Assessing Design Innovation. This study was in response to a request from the United Kingdom’s Department for Education and Skills (DfES) and the Department’s concerns that students project work and portfolios had become formulaic. Kimbell et al. (2004) argues that the Department was also concerned that as a result the work of innovative students who did not follow a formula may be penalised by comparison with those students who were well organised and did work to a formula. Further, Kimbell et al. claim that the Department’s study examined the extent to which innovation and team-work might be more fully recognised and rewarded in assessment processes and the manner in which this might achieved.

In phase 3 of the Kimbell et al. study, assessment activities that encouraged innovative student performance were developed. During this process students were guided by the teacher through a series of steps that were tightly timed. Within each of these steps the students had to record their thoughts in delineated sections of a pre-printed worksheet (Kimbell et al., 2004). This system is not dissimilar to the process of using ASIT (See 3.11) where the user is guided through a series of activities that lead to the development of a final solution. During this study Kimbell observed:

*There is a real counter-intuitive conundrum within this project ... At first glance it might be thought to be a bit like painting-by-numbers. And yet the comments of both teachers and students all talk of the freedom that students had to develop their own ideas.*

(Kimbell et al., 2004, 62)

Why is it then that when students are closely guided towards a final goal that they feel like they have more freedom than without the guidance? Kimbell noted that: *By taking away the need to think about how they [the students] will organise their work, they are empowered to concentrate [on their goal and] on the ideas that drive their designing* (Kimbell et al., 2004, 62).

The results of the Kimbell et al. study were examined during the observation stages of this research. It is posited that ASIT works in a similar manner to the directed approach employed in the Kimbell et al. research by focusing the problem-solver’s attention on the problem at hand. The question arises for this study is whether after pre-service Technology Education teachers apply the ASIT process whilst working towards a resolution of the given problem, they too will be *empowered to*
concentrate [on their goal and] on the ideas that drive their designing (Kimbell et al., 2004, 62)?

It can be seen from the preceding section that assessment and the process of facilitating students problem-solving appear to be linked. However, the precise nature of this link is not known with certainty. One feature that appears to be of importance to student problem-solving is the nature of strategies they use in attempting to solve design problems. These strategies are examined in the following section.

3.7 Problem-solving Strategies

The previous section examined the influence assessment practices have on the problem-solving process and outcomes in terms of the design production. In this section, the kinds of strategies, sometimes called heuristics, used to assist students in the process of designing are examined. There are two general ways by which humans solve problems. The first is referred to as an algorithm. Foulds (1983) (in Hatch, 1988) argues that algorithms are a procedure which guarantees a solution to a problem every time. A mathematical formula is an example of an algorithm. The second method is referred to as a heuristic. Heuristics are defined as strategies that increase the chances of a problem being solved; though, Payne (2001) states that they do not guarantee problem-solving success. Heuristics are sometimes called ‘rules of thumb’ strategies. The heuristic outlined in the sections on TRIZ and ASIT in 3.10 and 3.11 can be considered examples of strategies. It is argued here that Technology teacher education students need to develop and use a range of strategies in order to solve problems and to understand how these strategies can be used with their own students.

The Queensland Technology Syllabus Years 1 to 10 speaks of a ... learner-centred approach [which] provides opportunities for students to practice ... problem-solving ... when meeting design challenges (QSA, 2003, 10). However, the syllabus does not define the meaning of the process of problem-solving.

A number of definitions of problem-solving can be found in the literature. Hatch (1988) argues that a problem represents a situation where an obstruction prevents people from reaching their objectives. Hatch also contends that problem-solving is a
process through which people seek to resolve problems. However, Hatch qualifies this definition by arguing that the process of problem-solving varies depending on the type of problem that is identified. In addition, Deluca (1991) defines problem-solving as a process of resolving a known difficulty. In contrast, Anderson (1980) (in Deluca, 1991) argues that the process of problem-solving is a goal-directed activity and as such requires a sequence of operations or mental steps to resolve. However, Green (1989) would appear to disagree with the definition of Anderson and states that people prefer opportunistic planning and strategies such as trial-and-error rather than any fixed sequence of mental steps or operations such as top-down development.

Hatch (1988) argues that many of the problems encountered in the Technology Education classroom are … well structured … are relatively narrow in scope and usually have only one correct answer (Hatch, 1988, 89). Hatch suggests that this type of problem forces students to use convergent thinking. This is true perhaps if the student is trying to find the answer to a problem associated with a technological process such as determining the best speed to run a drill press for a particular material. However, many of the technological problems encountered require more complex solutions. Well-structured problems usually require only one correct answer and are solved by using simple algorithms. Foulds (1983) (in Hatch, 1988) notes that when applied to a problem, algorithms guarantee that a correct solution is determined.

Hatch states that semi-structured or ill-structured problems may have more than one correct answer and as a result algorithms are inappropriate strategies to apply and are best solved using problem-solving heuristics. Hatch argues that heuristics are strategies or guidelines that problem-solvers may find useful in solving semi-structured problems. However, the question remains as to what creative problem-solving strategies could be used and how design problems should be formulated in the Technology classroom. Further investigation is needed to identify if strategies such as ASIT are able to address the semi-structured and the ill-structured problems in the context of the Technology Education classroom. These questions are investigated further in this thesis.

The literature reviewed suggests that very little design problem-solving in the Technology Education classroom is achieved through any organised design process,
but rather a random experimental or trial-and-error approach appears to be favoured. As early as 1984, Bransford and Stein argued that most teachers are simply unaware of the basic process of problem-solving. Bransford and Stein maintain that this is despite frequently unconsciously using problem-solving processes themselves. As a result Bransford and Stein theorise that problem-solving is not learnt by students in schools because it is not taught by school teachers. Although Bransford and Stein arguments were written some time ago it appears that little has changed.

In a more recent study Warner (2002) concluded that in Queensland schools as few as 40 schools from a total 1150 had chosen to implement a Technology Education curriculum that incorporates problem-solving. It is possible this number has increased in recent years. It is argued that an explanation for the small number of schools adopting problem-solving based programs is the lack of creative problem-solving strategies available to teachers and the resulting apparent inability of teachers to assist students to produce creative solutions for design problems. One contribution of this study to practice is to attempt to provide a systematic design problem-solving approach for Technology Education classrooms through the introduction of ASIT, described in detail in 3.11.

### 3.8 Creative Cognition

The research of Finke, Ward and Smith (1992) reviewed creative thinking from a number of perspectives and methodologies and proposed a general model of investigation which was termed the Geneplore model. The Geneplore model combines both Generation and Exploration cognitive processes and provides a framework in which to describe basic cognitive processes.

In the cognitive context Generation procedures are described as those procedures that involve the creation of solutions or elements of a solution. Exploration procedures are those that explore the problem contexts and solutions or elements of a solution. Finke et al. argue that when a problem-solver cycles between the phases of Generation and Exploration they are typically engaged in creative thinking.
Middleton (1998) argues; however, that the theories of Finke et al. lack explicit reference to strategic control knowledge or metacognition (Gott, 1989) that is the manner in which a designer decides which procedures to employ and when. To create a more complete model by which to study cognitive processes Middleton combined both the Generation and Exploration cognitive processes of Finke et al. with the Executive control procedures of Gott.

Middleton contends that both Generation and Executive control procedures operate under the control of Executive Control procedures. Executive Control procedures are those concerned with planning, monitoring and evaluating what to do and when to do it. Middleton notes that the Generation/Exploration/Executive Control model advances the characterisation of both the way the designing process occurs and as a way of examining the design process that is more explanatory than the Gene Explore model of Finke et al. The Generation/Exploration/Executive Control model of Middleton is adopted in this thesis to investigate the cognitive procedures and processes deployed by the participants when solving technological problems.

Both of the studies reported in Chapters 5 and 6 present design challenges to the participants in a relatively controlled environment. Study 1 asks the participants to solve a technological problem using problem-solving strategies of their choice; though, some support is offered to the participants in the form of ‘Systemising Man-Made Objects’ worksheet. Study 2 also asks the participants to solve a technological problem; though, on this occasion it is specified that they are to apply the ASIT problem-solving process. Neither study specifically investigates the creativity of the solutions presented by the participants but seeks to reveal the cognitive procedures and process that they deploy when solving technological problems.

3.9 Analogical Thinking

Antonietti (2001) argues that … sometimes the solution of a novel problem is achieved by transferring a strategy derived from a familiar situation which is similar to the problem, even though it concerns a different domain (Antonietti, 2001, 7) and can be represented either in a verbal or a pictorial format. Antonietti notes that analogical problem-solving encourages the transfer of information, principles, or
insights from a familiar problem to an unfamiliar domain. When this transfer of knowledge or experience takes place, Antonietti (2001) argues that the problem-solver develops a new perspective of the familiar domain and finds unexpected meaning in the new domain.

However, Antonietti claims that this transfer is inconsistent and does not always occur. Antonietti believes that … some people fail to transfer spontaneously the solution procedure described in the source to the target if they are not instructed about the source-target relationship (Antonietti, 2001, 19). The problem types that Antonietti notes are the most likely problems to induce analogical problem-solving are those that are ill-defined in nature as they are open-ended and the goals are vaguely defined. Such problem types are typically found in the Technology Education classroom and are the subject of the studies reported in Chapters 5 and 6. Antonietti suggests that as a result of the vague solution descriptors of the ill-defined problem, it is not known what kind of information is important to solve the problem and that the possible solutions to the problem may vary greatly.

Antonietti reveals a number of factors relating to what he refers to as the transference from the source to the target. Firstly, if problem-solvers are not advised of the connection between the source solutions and principles and target problem then there is a low level of transference. Secondly, when problem-solvers are advised of the relevance of the source and that it might be useful to solve the target problem there was a high likelihood of transference and an analogical solution being proposed.

However, Antonietti argues that under certain conditions, such as when the source is similar in nature to the target, the problem-solver is able to transpose the solution principles described in the source to the target even though they were not given explicit hints or instructions to do so. Antonietti argues that this phenomenon occurs regardless of age and is found in adults and children alike. However, Antonietti notes that, by and large … providing source information only is not sufficient to induce subjects to make use of it to solve a new problem analogically (Antonietti, 2001, 21). According to Antonietti, this conclusion is consistent with the results of experiments in which, before the presentation of the target problems participants were exposed to information relevant to the solution of the targets.
Antonietti (2001) argues that in these studies problem-solvers were effective in solving problems only if they were informed of the connection between the information presented earlier and the targets. Antonietti noted that the problem-solvers … *failed to apply notions previously presented if strong cues to remind the prior analogous situations were not provided* (Antonietti, 2001, 21).

Antonietti argues that analogical problem-solving is based on the transfer of ideas from the familiar to the unfamiliar. In addition, that this process does not occur unless the problem-solver is able to realise the connections between the source and the new target problem and thereby draw analogies that result in a proposed solution to the problem. Antonietti concludes that analogical transfer not only depends on the contents of the source but may also rely on the processing functions that underlie the treatment of the sources. In addition, Antonietti states that analogical problem-solving has a role to play in reasoning by analogy and that reasoning is concerned with the process of … *coding and retrieval of information, categorisation, generalisation, inference, restructuring, etc.* (Antonietti, 2001, 7).

To test the theories of analogical problem-solving and transfer Antonietti conducted a series of studies with school children. Over a period of six months the students attended two weekly training sessions of approximately 90 minutes in length and were presented with a set of analogical thinking tasks. There was also a control group of students who did not receive any analogical problem-solving training. In each training session the students were presented with a series of short stories with similar underlying structures, although characters, places and situations may have varied. The students were asked to analyse, complete, vary or create analogies of the stories they had read.

Antonietti concluded that the results of the study indicate that students who had received anagogical problem-solving training recorded significantly higher number of solutions than the control group. As a result, Antonietti argues that problem-solving can be improved in the school environment by devising programs that … *train children to find correspondences, exploiting similarities, and transferring ideas from one situation to another* (Antonietti, 2001, 95).
Similarly, Kotovsky and Falside (1989) argue that the transference of ideas, information and knowledge is dependent on several key factors including: (a) the amount of representational overlap that exists between problems, (b) the greater the amount of representational overlap the greater the transfer, and (c) the locus of transfer is largely confined to the exploratory phase of the problem-solving process. Kotovsky and Falside contend that ... *it is the internal representation of a problem that determines transfer, and this representation can operate independently of the stimuli features of a problem* (Kotovsky and Falside, 1989, 105). Kotovsky and Falside note that by providing problem-solvers with problems that evoke particular representations the likelihood of transference occurring is increased and therefore usable in subsequent problem-solving experiences.

It is argued that the strategies of TRIZ and ASIT may be used to apply the principles of Antonietti (2001) and Kotovsky and Falside. TRIZ and ASIT are examined in the following section.

### 3.10 TRIZ

TRIZ is an acronym for the Russian words Teoriya Resheniya Izobretatelskikh Zadatch which when translated into English means the Theory of the Solution of Inventive Problems. Rawlinson (2001) argues that such problem-solving processes are known as structured thinking processes. Kaplan (1996a) describes the path that Altshuller undertook to develop the TRIZ problem-solving strategy. According to Kaplan, Altshuller (1990) first began to develop the TRIZ problem-solving system in 1950’s whilst working as a patents inspector in the Navy of the former Union of Soviet Socialist Republics (USSR). Kaplan notes that it was during this period that Altshuller studied thousands of patents, otherwise known in the USSR as ‘Inventors Certificates’, and as a result identified a number of underlying patterns of inventions.

Kaplan states that these patterns of inventions formed the basis of the problem-solving process that is now known as TRIZ. One of the underlying principles of the TRIZ process is the definition of an invention. TRIZ defines an invention as an idea that does not succumb to contradiction but rather progresses contradictions in a positive or favourable direction.
Kaplan (1996a) argues that during Altshuller’s (1990) research he came to the conclusion that the patents presented technical solutions that varied greatly in their degree of inventiveness. To illustrate this concept Altshuller formulated a scale of inventiveness or levels of inventive solutions. Kaplan defines the TRIZ Levels of Inventiveness as the following:

- **Level 1**: Standard - Solution by methods well known within specialty
- **Level 2**: Improvement - Improvement of an existing system, usually with some complication, Methods from the same industry
- **Level 3**: Invention inside Paradigm, Essential improvements of existing system, Methods from other fields
- **Level 4**: Invention outside Paradigm, Creating new generation of system, Solution not in technology, but in science
- **Level 5**: Discovery, Pioneer invention of an essentially new system, Usually based on major discovery, new science

(Kaplan, 1996, 2)

Malkin and Malkin (2003–04) illustrate the application of the TRIZ Levels of Inventiveness with the following example:

> A heavy machine vibrates excessively, creating problems in adjoining systems. A Level 1 solution for this problem might include placing a rubber pad under the machine to absorb the vibration. However, if this proves to be inadequate a second solution might be to compensate for the vibration using mechanical anti-vibration systems, a Level 3 solution. If both of these solutions are not appropriate the final solution to the vibration problem might be to isolate the machine from the support structure or floor using an air or magnetic "pillow," a Level 4 solution, and so on.

(Malkin and Malkin, 2003–04)

Altshuller concluded that an inventive solution involved overcoming the technical contradictions of the problem. TRIZ defines a technical contradiction as one where an attempt to improve one feature of the system causes the degradation of another feature. An example of this is when a driver increases the speed of a car fuel consumption is also increased. Altshuller found that engineers typically overcome technical contradictions in a design through a process of trade-off’s or compromises; however, Altshuller did not consider the results of such trade-offs to be inventions.

As Altshuller continued his research he made note of the technical contradictions that inventors had encountered and the principles the inventors had applied to overcome
the technical contradictions. This observation led Altshuller (1990) to develop a list of 39 engineering parameters including force, speed and strength and 40 operators that he called *Inventive Principles* for eliminating technical contradictions. Altshuller assembled the engineering parameters into a matrix of 39 rows (Improving Feature) x 39 columns (Worsening Feature). Contained in each of the intersecting cells is the list of Inventive Principles that inventors applied to the technical contradictions. This table is known as the Classical Contradiction Matrix and forms the core of the solution system used in Classical TRIZ. An excerpt can be seen below in Figure 6.

**Figure 6 Excerpt of Classical TRIZ Matrix**

In Figure 6 at the intersection of *Weight of moving object* and *Length of moving object* a cell with the following numbers can be seen, 8, 15, 29 and 34. These numbers represent the four TRIZ Inventive Principles that have been successfully applied to the *moving object* problem. These Inventive Principles are described below in chronological order with examples of solutions:

**Principles 8. Anti-weight**

*A. To compensate for the weight of an object, merge it with other objects that provide lift.*
Inject foaming agent into a bundle of logs, to make it float better.
Use helium balloon to support advertising signs.

B. To compensate for the weight of an object, make it interact with the environment (e.g. use aerodynamic, hydrodynamic, buoyancy and other forces).

Aircraft wing shape reduces air density above the wing, increases density below wing, to create lift. (This also demonstrates Principle 4, Asymmetry.)
Vortex strips improve lift of aircraft wings.
Hydrofoils lift ship out of the water to reduce drag.

Principle 15. Dynamics
A. Allow (or design) the characteristics of an object, external environment, or process to change to be optimal or to find an optimal operating condition.
Adjustable steering wheel (or seat, or back support, or mirror position.)

B. Divide an object into parts capable of movement relative to each other.

The "butterfly" computer keyboard, (also demonstrates Principle 7, "Nested doll").

C. If an object (or process) is rigid or inflexible, make it movable or adaptive.

The flexible boroscope for examining engines
The flexible sigmoidoscope, for medical examination

Principle 29. Pneumatics and hydraulics

A. Use gas and liquid parts of an object instead of solid parts (e.g. inflatable, filled with liquids, air cushion, hydrostatic, hydro-reactive).

Comfortable shoe sole inserts filled with gel
Store energy from decelerating a vehicle in a hydraulic system, then use the stored energy to accelerate later.

Principle 34. Discarding and recovering

A. Make portions of an object that have fulfilled their functions go away (discard by dissolving, evaporating, etc.) or modify these directly during operation.

Use a dissolving capsule for medicine.
Sprinkle water on cornstarch based packaging and watch it reduce its volume by more than 1000X
Ice structures: use water ice or carbon dioxide (dry ice) to make a template for a rammed earth structure, such as a temporary dam. Fill with earth, then, let the ice melt or sublime to leave the final structure.

B. Conversely, restore consumable parts of an object directly in operation.

Self-sharpening lawn mower blades
Automobile engines that give themselves a "tune up" while running (the ones that say "100,000 miles between tune ups")

(TRIZ Journal, 1997)

To arrive at a plausible solution the TRIZ practitioner must determine which of these solutions or combination of solutions, if any, is appropriate for the problem at hand. However, as mentioned earlier, TRIZ is not an algorithm but a strategy and therefore there is no guarantee that solutions listed in the Classical Contradiction Matrix will result in a solution to the problem being found.

3.10.1 1985 - Present Day

During the period from 1946–1985, Altshuller (1990) continued to develop the principles and concepts of the TRIZ problem-solving process; however, Altshuller did little research on patents and the application of TRIZ after 1985. This lack of continued exploration and development has limited the success of the Classical Contradiction Matrix as a problem-solving tool in more recent years (Mann et al., 2003). The rapid and constant development of technology and science since 1985 and the manner in which innovative solutions are applied to modern design and engineering problems has further hindered the effectiveness of the Classical Contradiction Matrix.

Mann et al. argue that there is a likelihood of between 10%–50% that a solution to a modern-day problem could be derived from the Classical Contradiction Matrix. Figure 7 below illustrates the probability of finding a solution to a problem for a number of domains.
The low rate of success has, however, led a small group of researchers (see (Mann et al., 2003) to investigate patents granted since 1985 and the problems and solutions contained within them. This has seen the development and enrichment of the 39 parameters of the original Classical Contradiction Matrix resulting in a new and re-sequenced Contradiction Matrix of 48 parameters. These are parameters are contained within the nine categories as follows:

1. **Amount of Information**
2. **Function Efficiency**
3. **Noise**
4. **Harmful Emissions**
5. **Compatibility/Connectability**
6. **Security**
7. **Safety/Vulnerability**
8. **Aesthetics**
9. **Control Complexity**

(Mann, et al., 2003, 6)

These nine new parameters were developed after researchers observed the manner in which modern inventors used and applied the original 40 Inventive Principles and how the application of these principles had changed since 1985.
3.11 TRIZ in Education

Sidorchuk and Khomenko (2006) have been teaching TRIZ in schools for a number of years and have published their observations and methods of teaching TRIZ. In the book *Thoughtivity for Kids* (2006), Sidorchuk and Khomenko outline a number of techniques and methods including the environmental conditions that they have found to be successful for teaching TRIZ in a primary school classroom.

To implement TRIZ successfully, Sidorchuk and Khomenko argue that it is necessary to create an environment that fosters the imaginative and creative qualities of students. Sidorchuk and Khomenko state that this can be achieved by creating a ‘safe culture of learning’ where students feel comfortable listening to each other and are happy that others are succeeding in their academic endeavors. Sidorchuk and Khomenko believe that, as a result, students will feel secure in taking risks and trying new ideas to develop new skills and knowledge. Education Queensland defines this safe culture of learning as one of ‘social support’. It is argued here that Technology teachers need specific strategies as well as general dispositions to create the appropriate learning environments for students to engage in design based technological problem-solving.

The investigation of TRIZ led the researcher to consider the observations, context and classroom modifications of Sidorchuk and Khomenko, the engineering origins of TRIZ and the resulting complexity of its structure and as a result concluded that TRIZ did not reflect the needs of the Technology classroom. In order to draw on the problem-solving concepts contained within TRIZ but in a form that would be more suitable over a wider range of technological problems, the system known by its acronym of ASIT was developed. A description of ASIT and its relevance to this thesis follows.

3.12 ASIT

The nature of Technology Education is to teach students to develop and design solutions to authentic technological problems and, as discussed earlier, this designing includes the use of problem-solving strategies. ASIT is one technological problem-solving process that may be able to provide students with the necessary tools and strategies to meet this need not only in the Technology classroom but also in other subjects across the school curriculum. This section firstly investigates the strategies
used in the ASIT methodology and it relationship with the TRIZ problem-solving strategy and secondly, the role ASIT has to play in the development of design solutions.

During the planning stage of this thesis a period of significant analysis of the TRIZ problem-solving strategy took place. As a result of this analysis it was determined by the researcher that the TRIZ problem-solving strategy did not adequately address the needs of the Technology classroom. It was realised; however, that many of the core concepts of the TRIZ problem-solving strategy are unique, leading the researcher to the conclusion that TRIZ as a problem-solving tool was an important and valid problem-solving strategy. The determination that TRIZ did not reflect the needs of the Technology classroom as a problem-solving tool led the researcher to investigate problem-solving strategies derived from the TRIZ process. During this period of investigation the researcher encountered a system known as the Advanced Systematic of Inventive Thinking (ASIT).

3.12.1 From TRIZ to ASIT

Horowitz (2001) started using TRIZ as a problem-solving strategy in the 1980’s and after many years as a TRIZ practitioner became aware of several shortfalls within the TRIZ system. Horowitz identified four essential areas where he believed the TRIZ methodology could be improved, these included: the ideal final Result, Resolving Contradiction, the 40 Principles and what Horowitz refers to as other TRIZ elements.

Horowitz analysed and transformed these four principles of TRIZ into the foundation of the ASIT problem-solving process: Firstly, the TRIZ Ideal Final Result became the ASIT Closed World. Secondly, Resolving Contradictions became Qualitative Change. Thirdly, the 40 principles of TRIZ were transformed into the ASIT five idea-provoking tools. Fourthly, Horowitz eliminated the remaining TRIZ elements. These four changes to the TRIZ system by Horowitz formed the basis for the development of the ASIT problem-solving strategy and are explained in more detail in the following section. An explanatory example of the application of ASIT problem-solving strategy developed by Horowitz can be found in section 3.11..2.
3.12.1.1 Step 1 - From Ideal Final Result to the Closed World Condition

Horowitz (2001) analysed the solutions to the technological problems he had produced and realised that none of these solutions involved the addition of any new components into the Problem World. Horowitz also noticed that although TRIZ encourages the problem-solver to use existing resources for solving a problem the principle was scattered around the TRIZ method. Horowitz cites the principle of the Ideal Final Result and several of the 40 Principles, such as Principle 25 - Self-service as those principles where this method of only using those elements from within the problem is applied. Horowitz argues that the Self-service principle calls for using an existing object to work upon itself instead of adding any new components.

Horowitz argues that the principle of using an existing object to work on itself instead of bringing in a new one (Horowitz) is the most important principle in the ASIT methodology and the key difference between ASIT and TRIZ. In addition, Horowitz refers to this principle as the Closed World and describes it as one where the solution can only be found from within the Problem World and the solution simply requires the reorganization of the existing objects. The Closed World principle focuses the problem-solver’s attention on the real problem and the components needed to solve the problem. In the following antenna example the problem is broken down and the true problem and contradiction is revealed:

A company that designed and manufactured receiving and transmitting systems was faced with a difficult problem, and they were hard-pressed to find a solution. They completed an assignment to produce a mobile system that included an antenna with a mast to support the antenna. The system was to be used by the army, and was designed so that it could be operated across the enemy line without someone activating it. This meant that it had to be operational for a long period of time before being discovered by the enemy. It was intended for a single soldier to carry the system to its destination, and it therefore had to be easy to carry. However, in extreme weather conditions, it was discovered that ice might accumulate on the antenna. The ice would not disturb the receiving and transmitting function, but it might create pressure on the mast supporting it, which could cause the whole system to collapse. How was this problem solved? It was discovered that by making the surface of the mast rough, the ice would accumulate on the mast as well as on the antenna! This idea is based on the fact that ice is a hard substance, and the idea was that the ice might strengthen the mast. The basic logic of the solution is that if there were no icy conditions, there would not be a need to strengthen the mast. However, if icy conditions prevailed, the strength required for the mast would appear by itself, and if the icy conditions were no longer present, there would no
longer be a need to strengthen the mast. The strength built up by itself (from the ice) would therefore disappear by itself.

(Introduction to ASIT, 2001, p 21)

Figure 8 illustrates the build up of ‘rime ice’ which in the ASIT solution is used to strengthen the antenna.

Figure 8 Rime Ice Antenna

(Rime Ice Antenna, 2011)

3.12.1.2 Step 2 - From Resolving Contradictions to Achieving Qualitative Change

The second of the changes Horowitz (2001) made was to transform the TRIZ principle of Resolving Contradictions to the ASIT principles of Achieving Qualitative Change. Horowitz argues that the: *Closed World condition deals with the resemblance between the Problem World and the Solution World* (Horowitz, 2001a). As a result Horowitz (2001) found it necessary to ... *establish the difference between the two worlds* (Horowitz, 2001a). To achieve this transformation Horowitz started with the TRIZ principle of Resolving Contradictions in which the practitioner looks to overcome a technical contradiction within a system. Such a situation exists when attempting to improve parameter ‘A’ where another parameter, ‘B’ is adversely affected. For example, in an attempt to make a component or product stronger by making it thicker it also gets heavier. According to Altshuller (1990) this is not an invention but rather a ‘trade-off’. This concept was redefined by Horowitz to become
ASIT’s Qualitative Change principle. The Qualitative Change principle is defined by Horowitz as looking … *for solutions in which the influence of the main problem factor is either totally eliminated or even reversed* (Horowitz, 2001a). The following example illustrates the ASIT Qualitative Change condition. In the Qualitative Change condition at least one aggravating factor in the problem world will change into a beneficial or neutral factor.

*Police all over the world need to deal with the ever-increasing problem of demonstrations and preventing crowds from entering certain areas. The police block off the area in advance using barricades, but due to the large crowds these barricades often topple over. …Recently, the Israeli police invented a new type of barricade that almost completely prevents the possibility of crowds breaking through the barricades into a secure area. [To solve this problem define the problem world first].*

**Problem objects:** crowd and barricades.

**Environmental objects:** secured area and perhaps additional police officers in the area.

[The unwanted situation in this example is connected to the crowds who overturn the barricades; the aggravating factor is the number of people.] … Conclusion: We want a solution that includes only objects such as barricades, crowd, area, policeman, and in which the more people at the demonstration, the less chance there is of breaking through the barricades, or a solution in which the number of people won’t affect this at all. In other words, in the required solution, the factor “number of people” changes from an aggravating factor into a beneficial or neutral factor.

*To start with, let’s assume that the number of people is a beneficial factor. A conclusion that can be drawn from this is that people who come to the demonstration, without their knowledge, or without their having any control over it, strengthen the barricades in some way. So how exactly does the crowd strengthen the barricades? Of course we can’t demand from them to perform a special act, and it’s therefore clear that by simply being there they are preventing the barricades from toppling over … by using their weight?*

*Let’s think about how we need to change the structure of the barricades so that the crowd will simply stand on some part of it. The barricades will look something like book ends.*

(Introduction to ASIT, 2001, p 41)

Presented in Figure 9 is an image of book-ends that illustrate the principle of the barricade solution. The solution in this case is that as the crowd pushes forward they
stand on the flat panel at the base of the barricade and as a consequence the crowds weight prevents the barricade from falling over.

**Figure 9 Book-ends**

![Figure 9: Book-ends](Marbig metal book-ends, 2011)

3.12..1.3 Step 3 - From the 40 principles to ASIT’s five idea-provoking tools

Horowitz (2001) concluded that the Closed World rule and the Qualitative Change rule were effective strategies for eliminating old ideas but they do not satisfy the need to create new ideas. With this in mind, Horowitz chose to look within the 40 TRIZ principles and the Contradiction Matrix for a solution.

As mentioned earlier the Classical Contradiction Matrix forms the core of the solution system used in Classical TRIZ. However, Horowitz noted there were several drawbacks to the matrix approach including the following:

*The principles do not operate on a uniform abstract level: Some of the principles are very general (e.g. Principle 17 - Another Dimension) and others are very problem-specific (e.g. Principle 18 - Mechanical Vibration, and Principle 29 - Pneumatics and Hydraulics). The frequency of use is not uniform: Some of the principles are used very often (e.g. Principle 17 - Another Dimension) and some are rarely used (e.g. Principle 7 - the Nested Doll)*

(Horowitz, 2001a)

Horowitz stated that TRIZ contained too many principles and that the large number of principles created its own problem by making it too difficult for the problem-solver to follow. In addition, Horowitz stated that the TRIZ approach was time consuming,
often with no solution being identified, and the variables are engineering focused and therefore limited in their scope. Horowitz (2001) also noted that due to the complexity of TRIZ it is not easily or quickly learnt and as a result, requires an extensive program of repetitive problem-solving exercises to learn each of the 40 principles. It is argued that a training program of this nature is not desirable in a Technology classroom, since the purposes are quite different to that of an engineering environment.

To overcome the practical limitations of TRIZ, Horowitz reduced the 40 TRIZ principles down to five and created the ASIT Five idea-provoking tools. This process included eliminating the ... principles that were too problem-specific, principles that are not used very often, [and grouped] ... similar principles together (Horowitz, 2001a). These changes lead to the developments of the following rules:

Unification: Solve a problem by assigning a new use to an existing component.

Multiplication: Solve a problem by introducing a slightly modified copy of an existing object into the current system.

Division: Solve a problem by dividing an object and reorganizing its parts.

Breaking Symmetry: Solve a problem by turning a symmetrical situation into an asymmetrical one.

Object Removal: Solve a problem by removing an object from the system and assigning its action to another existing object.

(Horowitz, 2001a)

The five idea-provoking tools replace the complex and limited Classical Contradiction Matrix of TRIZ and form the basis of the ASIT system.

3.12.1.4 Step 4 - Eliminating other TRIZ elements

When the researcher was reviewing the ASIT problem-solving strategy and compared it to TRIZ it became evident that Horowitz did not attempt to replicate all of the principles and processes of TRIZ. It appears that Horowitz did simplify and condense them to form ASIT. This simplification and condensation eliminated three of the TRIZ elements. The eliminated principles included the following: Standard solutions and physical effects, Evolution of systems, and The Little Man method. Each of these
principles contained ... ready-made, highly domain-specific standard solutions and physical effects (Horowitz, 2001a). Horowitz (2001) argued that although these principles were important to an engineer in trying to solve tough problems it was necessary to eliminate them to ... keep ASIT as a pure thinking (as opposed to knowledge) tool... (Horowitz, 2001a).

It is apparent from the work of Horowitz that the intention was not to replace Classical TRIZ but rather continue with the evolution of TRIZ, transforming it into a more user-friendly and versatile problem-solving methodology and in doing so Horowitz has developed what is thought to be a more universally applicable problem-solving tool. It is for these reasons that ASIT was chosen as the problem-solving process to be applied in Study 2.

3.12.2 Applying ASIT
The following section illustrates how ASIT might be applied to solve a contemporary design problem. The researcher applied the ASIT problem-solving strategy to a known health and environmental problem. In this case the problem chosen was the treatment of domestic grey-water or wastewater in rural areas. Wastewater in this context is the generic term used to describe all used water from the kitchen, toilet, bathroom and laundry drains. In many rural areas there are no underground community wastewater treatment facilities available and consumers have a limited choice of commercially available alternatives.

To establish the foundation for the wastewater investigation the researcher reviewed the methods in which existing popular wastewater treatment systems managed and processed domestic wastewater. The following section describes the manner in which a typical septic wastewater treatment systems works. The term septic refers to the anaerobic bacterial environment that develops in the tank and aids in the decomposition or mineralisation of wastewater in the tank.
3.12.3 Septic Tank Wastewater System

In the typical wastewater system all untreated household wastewater flows into a septic tank where settlement and primary breakdown of waste material takes place. Some lighter solids float to the top and heavier solids sink to the bottom of the tank. Anaerobic bacteria help to digest the solids. To maintain the bacterial ecosystem it is necessary to break down the waste material further with the use of several aerating pumps. These pumps aerate the wastewater, creating bubbles and as a result the bubbles increase the surface area of the waste material. This larger surface area allows a greater population of bacteria to reside on the surface of the bubbles which helps to improve the efficiency of the system to break down the waste material. The septic system needs the aerating pumps to run continuously thereby increasing the energy consumption and complexity of the system. However, this aeration system does not guarantee that the micro-organisms will consume all of the waste.

The remaining liquid is then pumped from the first septic tank into a second tank where it undergoes yet another process, that of disinfection. Disinfection is performed with the addition of chemicals, such as chlorine to kill any remaining pathogens. Alternatively, a process whereby the liquid is exposed to high levels of artificially generated ultraviolet radiation can also be used. After disinfection the remaining liquids are pumped out of the second tank into a land drainage system or irrigation system known as a drainfield. Any remaining unprocessed solids are held in the tank by a series of baffles preventing them from polluting and clogging the soil. Clogging of the soil can limit the ability of the soil to properly treat the septic tank effluent. It is generally recommended by the manufacturers of these systems and the regulatory bodies that monitor their performance, that any remaining sludge be pumped out annually and that the system is inspected every three to five years by a qualified maintenance operator. These additional maintenance and chemical expenses adds to the overall running costs of these systems. Problems that were identified with the septic tank system include: expensive mechanical aerators to run, maintain and replace; continuous electricity consumption; routine cleaning and pumping out of the tanks; costly maintenance schedule; high likelihood of polluting or clogging the drainfield. With these design and maintenance issues in mind alternatives to the septic tank system were investigated.
The result of further investigation revealed a number of bio-organic wastewater treatment systems. Bio-organic wastewater designers and engineers looked to nature for inspiration and ideas to solve the wastewater problems of the septic tank system. They found the answer in a natural environment where solid compost is continually being broken down - that of the forest floor. Figure 10 illustrates how one bio-organic wastewater system uses the principles of nature to solve this problem.

**Figure 10 Illustration of the Biolytix® Filtration System**

(Biolytix, 2011)

### 3.12.4 ASIT and the Bio-organic Wastewater System

The following example demonstrates how problem-solving might apply ASIT to solve the inherent problems of the septic wastewater tank system and arrive at a plausible solution to the problem. The example focuses on the application of the ASIT Division Rule. Horowitz (2001) argues that the ASIT Division Rule reveals formerly hidden sub-objects and the connections and relationship between them. According to
Horowitz (2001), to initiate the Division Rule the problem-solver must choose an object, identify its parts and re-organise these parts. To understand how to apply the Division Rule to the septic tank system the problem-solver must first select the object - in this case the design engineers chose the natural forest floor ecosystem. The design engineers determined that the forest floor was an efficient waste management system that delivered the outcomes that they desired in their design solution.

The ecosystem of the natural forest floor consists of numerous components including macro and micro organisms such as worms, grubs, beetles and bacteria and the environment in which these objects can be found including leaf debris, animal waste and water. The next step is to solve the problem while making a change to the object/objects of the forest floor or the ways in which the objects are handled. This can be achieved in two ways:

(A) Parts of the forest floor environment - including organic matter, moisture, temperature
(B) Parts of the insect population that lives within the forest floor environment - macro and micro organisms including: worms, grubs insects, insects and bacteria

At this stage the problem-solver needs to choose the division that is to be focused on. Once this is done the problem-solver needs to complete the following sentence: The object will be divided into (list of parts) and will be reorganised in space or time. In this case, the sentence will read: The forest floor ecosystem will be divided into the environmental elements (including moisture, temperature, oxygen), the organic matter and the insect population and will be reorganised in space or time. This sentence creates the environment for further ideas to develop; however, more work is needed to produce the final solution.

The bio-organic wastewater system mimics the natural processes of composting as is done on the forest floor. In this example the solid waste material is immediately separated from any liquid. Macro-organisms such as worms consume the solid
material and convert it to fine humus like material which forms a humus bed. Due to
the efficient manner in which worms transform the solid material into the humus like
material it is not necessary to add large aerating pumps or chemicals at any stage
during the process. The fine humus like material produced is structured by soil macro-
organisms into a sponge-like porous filter medium. The humus acts like a large lung
and oxygenates the wastewater as it trickles through the medium and creates an ideal
environment for the biolytic process to take place. When the wastewater finally
reaches the bottom of the tank all solids have been removed and the wastewater has
been cleaned by the biolytic organisms.

The final stage of the bio-organic system is to filter the remaining wastewater through
a geofabric filter which is a semi-permeable material. The geofabric filter removes all
particles larger than 80 micron from the remaining wastewater. The remaining
wastewater is then pumped out through a drainfield using a small inexpensive pump.

The bio-organic wastewater treatment system differs from the more common septic
tank system in a number of ways, including: no large expensive mechanical aerators
to run, maintain and replace; lower energy running costs; no routine cleaning and
pumping out of the tanks; reduced costly maintenance schedule; less likelihood of
polluting or clogging the drainfield. A number of additional benefits were also
realized: virtually odorless because there is no septic stage; household food waste can
also be treated in the system; no risk of pathogen exposure in the irrigation system;
reduced methane emissions; chemical free - no hazardous chemicals to handle or
dispose of into the soil.

Although it is not known what technological problem-solving strategies the engineers
and designers of the bio-organic wastewater treatment system employed to achieve
their final design solution, this example serves to demonstrate how ASIT tools can be
applied retrospectively to technological problems. In addition, the example provides
an application model that can be used in the school and tertiary Technology classroom
to demonstrate the numerous ways in which the ASIT rules can be applied to arrive at
appropriate design solutions.
3.13 Conclusion

It is argued in Chapter 3 that the Technology Key Learning Area (KLA) represents a new approach to engage students in problem-solving. Problem-solving finds its basis in cognitive theory. In the classroom the shift from traditional teacher directed learning approaches to one of a student-focused facilitator approach represents a significant change in practice and thinking for Technology Education students and teachers. Four factors that are seen to influence the change in pedagogy to a problem-solving approach in Technology are examined in this chapter.

The literature examining the difficulties of moving from a teacher directed approach to a student focused design based approach argues that the traditional instructional methodology of previous centuries is failing students in the 21st century classroom. Schwartz (2003) argues that traditional instructional methodologies do not allow students to be self-directed learners but rather focuses their attention on following the directions of the teacher. It is argued that in this context the design brief has a significant role to play in fostering this change. Although the content of the design brief is determined by the teacher the students determine what strategies and activities are appropriate to meet the design goals. As Zuga and Bjorkquist (1989) note; however, it is important that the design brief does not become a method of creating learning activities that are little more than ‘high tech’ traditional instructional processes. Zuga and Bjorkquist claim that it is the manner in which a course is organised, delivered and taught that creates the opportunity for students to become independent thinkers and problem-solvers.

Lewis (1999) argues that the Technology learning environment is a unique one where students are allowed to talk freely to discuss with fellow students their learning activities, the strategies and techniques that each is applying and discuss the goals of the design challenges openly with the teacher. Sidorchuk and Khomenko (2006) suggest that a social atmosphere such as that found in the Technology classroom provides an ideal opportunity to provide an environment that is a safe ‘culture of learning’. Sidorchuk and Khomenko argue that when taken into account these factors provide an ideal environment to create a successful Technology classroom.
Bransford and Stein (1984), Warner (2001) and others maintain that the transition from the traditional Industrial Arts/Manual Arts instructional methodologies to the student focused problem-solving environment of the Technology classroom is slow to occur. The reasons for this have not been completely identified; however, it is argued that issues such as the age and training of teachers, the lack of experience in the Technology teaching area, the inability to create a suitable learning environment and a lack of suitable problem-solving strategies on the part of the teachers are contributing factors.

Wu et al. (1996) argue that due to the unique nature of the ill-defined Technology problems encountered in the Technology classroom, generic problem-solving skills are insufficient and that specific problem-solving strategies are needed. Wu et al. suggests that the earlier in the student’s academic career these problem-solving strategies are introduced the more encouraged they will become to explore and interact with the technological world in which they live. However, although it is recognised that problem-solving strategies that are appropriate for the unique nature of ill-defined technological problems are needed, the literature makes no suggestions as to what such a problem-solving strategy may be or include.

The lack of suitable technological problem-solving strategies led to the investigation of several problem-solving strategies. In the high school environment there is a close relationship between Technology and engineering content in the classroom and the two areas are often taught by the same teaching staff. As a result engineering problem-solving strategies such as TRIZ may also be appropriate for use in the Technology classroom. However, the investigation found that TRIZ, with engineering problems and solutions at its core, required a level of user expertise that is unattainable in the Technology classroom. Further investigation led to the analysis of similar problem-solving strategies and as a result ASIT was examined. ASIT has its roots in the TRIZ process and shared similar outcomes to that of TRIZ. However, it is argued that ASIT is simpler to use, more versatile and had greater functionality when applied to the ill-defined problems of the Technology classroom.

To interpret the cognitive processes that are deployed by problem-solvers when engaged in technological problem-solving the work of Finke, Ward and Smith (1992)
and Stevenson (1991) was examined. Finke et al. (1992) propose that a cognitive model that includes the Generation and Exploration processes provides a framework by which basic cognitive processes can be described. These cognitive processes describe the manner in which problem-solvers explore and generated the attributes of a problem and solutions that might resolve the problem. However, Stevenson argues that these cognitive processes operate under the guidance of Executive Control procedures and that Executive Control procedures are deployed by the problem-solver to determine what to do and when to do it.

The examination of literature revealed a number of gaps and implications for the kind of empirical study undertaken and described in Chapter 4 and reported on in Chapters 5 and 6. These gaps included: (a) what strategies pre-service Technology teachers use to solve technological problems, (b) what implications do the ASIT problem-solving strategy have for solving complex technological problems by pre-service Technology teachers and (c) are these strategies suitable as teaching methods for use in school settings.
CHAPTER 4

RESEARCH METHODOLOGY

4 INTRODUCTION

One aim of the research in this thesis is to examine the nature of technological problems and the way in which pre-service Technology teachers solve them. A second aim is to examine the pedagogical approaches that pre-service Technology teachers use to assist students to solve design based technological problems. An important aspect of this aim is to investigate the role of specific strategies employed by pre-service teachers in solving design based technological problems. This chapter describes and justifies the research methods used in examining the arguments advanced in Chapters 2 and 3 and reported on in Chapters 5 and 6.

The questions examined in this thesis are concerned with how pre-service Technology teacher solve design based technological problems and the utility of the strategies they employ to solve these problems, as pedagogical tools. In addition, the nature and role of specific strategies, (also described as heuristics or procedures) in the problem-solving process are examined. The questions are examined in the studies reported in Chapters 5 and 6 in terms of the deployment of cognitive procedures.

4.1 Predictions

The predictions being tested in this investigation are: (1) Design based technological problems are complex because they contain a large search space (Newell and Simon, 1972) and require creative solutions; (2) The use of heuristic or strategies improves the chances of a solution to a problem being produced; (3) Particular strategies provide the basis of a pedagogical approach to teaching design based technological problem-solving in school settings.

In order to answer these research questions, a study was conducted that involved examining pre-service Technology teachers’ problem-solving activities across two studies. Two sets of data were collected and analysed. These records of contemporary
students’ design based technological problem-solving and the solutions they created were collected and examined to establish the effect of specific strategies on the process students engaged in when solving a design problem. (1) Video footage and audio soundtracks of participants verbalisations were recorded and analysed to establish design solution strategies: (2) Hardcopy images and sketches of students design based technological solutions were also collected and analysed. Thus both textual (words) and imaginal (sketches and video recording of solutions and of visual expression) data were collected. In addition, the sound component of the video recordings were used to assist in interpreting transcripts because they allowed such features as tone of voice and intonation to be used in determining coding. The purpose of the three sets of data was to provide the basis for examining the underlying question of how Technology students attempt to accomplish their goals through specific behaviours in specific environments (Patton, 1990).

4.2 Research Approach

The approach taken in the two studies described here and reported on in Chapters 5 and 6 is case study. That is, a limited number of participants engaging in the activities to be studied were examined and a rich data source obtained. The Technology problems presented to the participants in this thesis are regarded as ill-defined in nature, complex and difficult to solve. Stoyanov and Kirschner (2007) argue that ill-defined problems are characterised by ... incomplete data or insufficient access to information, existence of alternative and often conflicting approaches, lack of clear-cut problem-solving procedure and no agreement upon what can be accepted as appropriate solution (Jonassen, 2004; Schön, 1996; Wagner, 1992; in Stoyanov and Kirschner, 2007).

Technology problems involve a series of complex interactions between many variables both predictable and unpredictable, to achieve resolution. The design problems employed in Studies 1 and 2 reflected these complexities and as a result a particular ethnographic research approach and methodology has been utilised. This thesis examined, in detail, the design problem-solving activities and procedures of three pre-service Technology teachers and seeks to explain the … multiplicities of reasons that would account for a specific behaviour (Babbie, 1995, 67). As a result
this thesis is considered an ethnographical model of explanation. The complexities of Studies 1 and 2 make it inappropriate to disaggregate the problem-solving process to allow more quantitative methods to be employed (Gay, 1996; Yin, 1994).

Creswell (2008) argues that an ethnographic case study is the ... in-depth exploration of a bounded system and may include the ... analysis of a person, event, activity, or process set within a cultural perspective (Creswell, 2008, 475). In this context Creswell states that ... bounded means that the case is separated out for research in terms of time, place or some physical boundaries (Creswell, 2008, 476). The case studies in this thesis illustrate a study of three bounded systems, that of specific individual participants, and the analysis of cognitive patterns of problem-solving behaviour for each individual and for all three participants. In this thesis qualitative methods are supported by descriptive statistics in each of the case studies. The description and explanation of the cognitive procedures deployed by each of the participants is qualitative in nature which is supported by evidence of patterns of change amongst the participants’ cognitive procedures.

To facilitate the research undertaken in this thesis a number of data media were collected, including; artefacts, video footage and audio soundtracks of participants activities and design solutions. In addition, hardcopies of written responses to design briefs and sketches of design solutions were also collected and analysed to provide imaginal data to assist in interpreting verbal data. The purpose of collecting this rich data source was to examine the problem-solving strategies employed by pre-service Technology teachers when solving technological problems.

In terms of comparability of data, all participants were enrolled in the same Technology program, each of the participants was in the same year of their program, each of the participants had received the same amount of tuition on problem-solving and problem-solving strategies and each of the participants was provided with identical design briefs for Studies 1 and 2 and the participants were allowed the same amount of time to complete the design challenges. However, it must be acknowledged that for the generalisations of the findings of this research into technological problem-solving further studies that involve a greater number of participants and therefore more replication will be necessary.
4.3 Chapter Purpose and Structure

The purpose of this chapter is to provide a comprehensive explanation and justification of the research design and data analysis employed in the two studies that constitute the empirical section of the thesis. The research design of Study 1 involved a detailed examination of contemporary university students’ problem-solving strategies when solving technological design problems and when given a free choice of problem-solving strategy. Study 2 involved an examination of the same group of students’ problem-solving actions when applying the ASIT problem-solving strategy. The analysis of the problem-solving strategies employed by students in Studies 1 and 2 examined the nature of cognitive procedures employed in solving design based technological problems. The analysis of visual data was used to clarify and strengthen the analysis of and conclusions drawn from, the verbal data.

The chapter is divided into four sections. The first section describes the research approach taken to investigate in detail, the design problem-solving activities and procedures of three pre-service Technology teachers. The second section presents the background to the study and provides in-depth information regarding the preparation of the participants for the study including the stages in which ASIT was introduced. The third section describes the methods used to collect data and provides justification for the analysis and interpretation of findings and conclusions of the study. Finally, the last section discusses the strengths and limitations of research design and highlights the steps taken to minimise the threats to validity and reliability.

4.4 Design of the Case Studies

The design of the study comprises two related but different case studies. Both Study 1 and Study 2 examined the data generated by third year pre-service teachers enrolled in a Bachelor of Technology Education (BTechEd) teaching degree at Griffith University. As noted, the research comprised two case studies: Study 1 was based on a Sustainability and Packaging Design problem where students used their choice of problem-solving strategy. Study 2 was based on a Brisbane Library case study problem which was solved using the ASIT problem-solving process. A description of Study 1 and Study 2 follows.
4.5 Selection of Participants

The selection process of these students was based on five criteria:

1. Participants were full time third year student teachers enrolled in the Bachelor of Technology Education (BTechEd). This was a requirement because the study was specific to pre-service Technology teachers. Third year students were selected for two reasons. Firstly, it was regarded as important to collect data from students who had had a substantial experience of the Technology Education degree as they were considered expert technological problem-solves. Secondly, it was regarded as important to avoid final year students, given the stress encountered by students during this year and the possible compounding effect this may have had on the data generated by such a group.

2. Participants had been previously instructed in the ASIT problem-solving process and its application prior to commencing Study 1. This was necessary to establish the effect of this instruction on their problem-solving activity.

3. Participants had previous experience solving design and technological problems. This was regarded as necessary to avoid the use of students who were more familiar with directed modes of learning and unused to solving technological problems. Students unused to solving technological problems may simply report being unable to proceed with the problem-solving activity.

4. Participants were comfortable verbally expressing their thoughts and actions while being recorded. Ericsson and Simon (1993) argue that for verbal protocol analysis to be effective as a data collection method, participants had to feel comfortable expressing their thoughts about the activity they were engaged in. If this was not the case Ericsson and Simon (1993) believe that the effort of verbalising would change the nature of the verbalisations, negatively affecting its quality.

5. Participants agreed to take part in both studies. This was necessary from both an ethical standpoint and to ensure comparison of problem-solving performance across activities. That is, it was necessary to be able to compare how students solved a technological problem when given a free choice of methods and to be able to compare that with the same student using the ASIT method. This had to be established at the outset.
As a result of the selection criteria outlined above, three of the 14 students in the third year cohort were identified as possessing all of the necessary traits needed for Study 1 and 2. This was regarded as a sufficient number of participants for the study as there was an expectation that they would produce a rich supply of data of various kinds. This was in fact what happened. Middleton (1998) established that when engaging in complex tasks such as technological problem-solving that a rich source of visual and verbal data is generated. Middleton maintains that this rich data source provides ample material for a study of this kind. The profiles of the three participants can be seen below.

**Participant B**
Participant B was a 22-year-old male, third year student, and was a high school graduate when first enrolled in the BTechEd program as a student teacher. Participant B had no previous trade or technical training experience or qualifications.

**Participant G**
Participant G was a 28-year-old male, third year student, enrolled in the BTechEd student teacher program. Participant G had a formal trade qualification as an auto-mechanic.

**Participant P**
Participant P was a 34-year-old male, third year student, enrolled in the BTechEd student teacher program. Participant P had a formal trade qualification as a cabinet maker.

### 4.6 Settings
Participant protocols from Studies 1 and 2 were collected during a scheduled Curriculum Development class which was conducted in a quiet design-studio that was familiar to the three participants. The design-studio was a setting where design and technology activities normally occurred and was adjacent to the main curriculum development class. Some verbalisations from the three participants and research assistants were audible at times. To avoid possible distraction, the participants were positioned around the design-studio. This was done to minimise any interference that
may occur between the participants or research assistants while undergoing the design challenges. The participants were located in the following manner: Participant B was situated at a desk at the front and right of the room facing a wall with his back to the other participants while Participant G was situated at a desk facing a wall towards the back of the room and Participant P was situated at a desk at the front and left of the room facing a wall with his back to the other participants.

4.7 Background to the Studies

In 2008, technological problem-solving was introduced to the first year cohort of students studying a Bachelor of Technology Education at Griffith University. Study 1 and 2 in 2010 was comprised of students from the same cohort. The setting and context for the introduction of the technological problem-solving was a course entitled Design Processes. This is a foundation course in the degree program and the students’ first introduction to design within the program. This course covers many of the elements of three-dimensional design including: graphics and graphics design principles, materials and the technical, ecological and aesthetic elements of design. In addition, Design Processes covers the pedagogical strategies necessary for the introduction of design methods in schools (Course Outline, 2008). It was judged that this course would be the most appropriate course for the introduction of technological problem-solving process.

The students orientation with the technological problem-solving process began with the introduction and explanation of the methods of research employed to monitor the social environment of the class, the role of the teacher, and the impact of technological problem-solving on creative problem-solving performance. Two alternative strategies to technological problem-solving were introduced to the students and discussed in class. Firstly, product feature analysis was discussed and exercises that examined the past, present and future design of a man-made product were performed by the students. The structure of the product feature analysis was detailed in the worksheet entitled Systemising Man-made Objects as seen in Table 1 below:
The Systemising Man-made Objects worksheet was derived from a similar table found in *Thoughtivity for Kids* (Sidorchuk and Khomenko, 2006).

Secondly, the researcher delivered the ASIT problem-solving material to the 2008 class of students. The delivery of the ASIT problem-solving strategy was achieved through the introduction of background information, exercises and design challenges. The aim of the exercises and design challenges and the timing of their introduction were regarded as crucial to the success of the research process in Case study 2. The exercise and design challenges performed during weeks 1, 2 and 3 of the course were designed to question the participants’ prior assumptions about the methods by which they solved problems and the solutions that they developed through the problem-solving process. The following illustrates the timelines in which the ASIT problem-solving strategy was introduced to the students.

<table>
<thead>
<tr>
<th>Week 4 Introduction to basic principles of ASIT</th>
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<tbody>
<tr>
<td><strong>Table 1 Systemising Man-Made Objects</strong></td>
</tr>
<tr>
<td><strong>Systemising Man-Made Objects</strong></td>
</tr>
<tr>
<td>1. Name the environment in which the function of the object is carried out in the past</td>
</tr>
<tr>
<td>2. Describe the object and determine its function in the past</td>
</tr>
<tr>
<td>3. Label the parts of the object which assist it in carrying out its function in the past</td>
</tr>
</tbody>
</table>
Weeks 5 and 6 Interactive workshops on ASIT where the process of action research was employed to implement, reflect on, refine and adjust the approach taken. These workshops also included discussion of examples of ASIT solutions from the research literature. Students developed solutions to problems presented in tutorials during weeks 6, 7 and 8.

Week 10 Presentation of Major Project design brief to be solved using an ASIT process.

Week 13 Submission of ASIT based solution to Major Project brief.

The exercise and design challenges introduced in weeks 5 and 6 were conducted in a classroom environment under the supervision of the researcher. The aim of these exercises was to demonstrate the process of applying the ASIT rules to the resolution of particular problems. It was envisaged that this would allow the participants to explore where and in what circumstances the five ASIT rules could be applied and to provide the opportunity to discuss these choices in an open forum with their peers and the researcher. Finally, the students were to design and manufacture a major project that was included in the published assessment items of the course. The focus of the major project was to highlight the application of the individual ASIT and how these rules could be applied to a particular design problem. It was envisaged the participants may develop several solutions to a particular problem.

2009: A follow up ASIT course was conducted during the first semester of 2009 with the students who participated in Design Processes in 2008. These students were in the second year of their undergraduate degree and enrolled in a pedagogy course. It should be noted that of the 16 students originally enrolled in Design Processes only 14 of these were enrolled in the pedagogy course.

During the final tutorial of the pedagogy course the participants were re-introduced to the problem-solving strategies and rules of ASIT. This class content was structured as follows:

- Re-introduce participants to the problem-solving strategies and rules of ASIT
Discussion regarding the application of ASIT

Introduction and discussion of the design problem

A 2000 word essay formed part of the assessment of this course. In this essay participants were asked to reflect on the impact ASIT had made on their designing and problem-solving processes during the past year and how they would teach it in a secondary classroom, including strategies and examples.

4.8 Selection of the Design Problems

The aim of the design problems selected for Study 1 and Study 2 was to fulfil three objectives. Firstly, it was necessary that the problems required significant effort for tertiary students to solve. That is, the aim was to have students attempt to solve a problem that was, in some respects, new to them and could not be solved by them using existing tacit knowledge. Polanyi (1966) argues that, by definition, tacit knowledge is knowledge that cannot be verbalised.

Secondly, the problems needed to be within the capacity of the students yet represent authentic design challenges that could be used in a secondary high school classroom. That is, they had to be problems the students would see as relevant to their learning activities as students preparing to become Technology teachers.

Thirdly, the solutions to the design problem had to be achievable within the time constraints of university timetables and constraints in terms of availability of equipment and resources. Finally, the design challenges had to contain a number of complex and contradictory constraints that would ensure that problem-solvers of all levels of experience and knowledge would encounter difficulty when solving the problem. This was necessary to ensure that during Studies 1 and 2 problem-solvers would not be able to use tacit knowledge. If participants were able to use tacit knowledge two problems would arise. Firstly, the problem would be considered too simple, and secondly, no verbal data would be generated.

In order to achieve the degree of complexity required to limit the use of tacit knowledge and automated or known problem-solving strategies by the participants a
number of measures were considered. These measures included creating design briefs that were ill-defined, where some aspects of the problem were vaguely stated and that were knowledge rich, in that a lot of prior knowledge was needed to solve the problem (Robertson, 2001). In addition, the technological problem type required the problem-solver to be semantically rich where he/she can bring to bear a lot of experience of the problem type (Robertson). The design briefs also required that the problem-solver be able to interpret and classify the problem or sub-problems in terms of the strategies needed to solve them (Payne, 2001).

More generally, it was important for participants to be solving complex problems because the development of the ability to do so is an important outcome of Technology Education programs at both school and university levels. The identification of these difficulties might therefore reveal the problem-solving strategies deployed by the participants while engaged in the design challenge.

The design briefs chosen for Studies 1 and 2 were similar in that both studies contained contradictory requirements; however, the format, information and the requirements of the design briefs were significantly different. The design brief of Study 1 focused the participants problem-solving activities on a sustainability and packaging design challenge. Barlex et al. (1995) would argue that the Sustainability and Packaging design brief is ‘closed’ in nature as it outlines the problem within a context, defines the solution to the problem and stipulates what materials and criteria are to be used to achieve the solution. Observations, by the thesis author, of teaching practice in both the tertiary and school context finds that this style of design brief is typical of those used.

In Study 1, the primary contradictory constraints of the design brief were to design and manufacture packaging for a standard household lightbulb using only one sheet of A3 copier paper. This design brief was inspired by one described by Kimbell et al. (2004). The packaging solution was then to be reused as a light/lamp shade and the design challenge was to be completed in one hour. The Sustainability and Packaging design Brief was to be completed using only the selection of materials presented to the participants and included equipment and materials such as paper, scissors, glue, staples, pens and pencils and other miscellaneous materials. In addition, due to the
nature of the design challenge, it was expected that unforeseen design conflicts and solution problems would arise during the designing and manufacturing process. Robertson (2001) argues that where some aspects of a problem are only vaguely stated that the problem is ill-defined in nature. In this case the design brief does not stipulate what strategies or tasks are to be carried out in order to achieve a plausible solution to the problem and it is therefore considered ill-defined.

In contrast, Barlex et al. (1995) would argue that the design brief of Study 2 is ‘open’ in nature as it allows the designer the flexibility to freely experiment with designs and solutions to a design problem. However, it is considered ill-defined as it only vaguely states some aspects of the problem. The primary contradictory requirement of Study 2 was the need to design a solution to moving the entire library book collection from the old Brisbane Library to the new Brisbane Library given that there were insufficient funds available for this to be achieved by a Removalist company. Unlike the design brief for Study 1 where participants were given detailed information regarding the design challenge, the design brief for the Brisbane Library design challenge revealed very little information or detail as to the conditions or constraints that might be considered by the participants when designing their solution to the design challenge. Nor did the design brief give the participants any information or clues as to how this goal might be achieved. The information that the participants were given in the design brief was limited, providing only the basic constraints of the problem.

The open nature of Study 2 did allow the participants the autonomy to choose what the solution to the problem would be and what materials or resources were to be used. The participants also had the freedom to resolve the problem by generating only one or a number of solutions to the problem. In addition, there were also no limitations in the design brief on whether or not the participants could create prototypes or models to assist with problem-solving. Finally, the design brief for the Brisbane Library problem did not forecast or reveal what effects and impacts their solution might have as it was thought that the limitations of their designs would be tested by the application the ASIT problem-solving strategy.

Both design challenges were of a kind that participants would be expected to encounter during their studies and were both considered design challenges the
participants would regard as authentic in the context of their studies. The following design briefs for Study 1 and 2 were supplied to the participants:

4.9 Study 1 - Sustainability and Packaging Design Brief

The Design Brief

Problem Context
Most packaging for the goods we buy is discarded after we have un-wrapped the products and ends up wasted in landfill. In an effort to save our valuable resources and reduce waste the packaging must become re usable.

Design Challenge

Your challenge is to design and make packaging for a light bulb that can also be used as the light shade/lamp shade for the same light bulb.

Inclusion

- You are given a selection of paper and equipment such as light bulb, scissors, glue, staplers etc. [sic] to complete the challenge.
- You are to work on the design challenge individually (this is not a team challenge).
- At the end of the design challenge students are asked to present their solution and discuss the designing and making issues they encountered and how they were solved.
- Students are encouraged to ask 'teacher' questions of the student presenting to draw out more information about their design solution.
- You have 1 hour to complete the design challenge.

In addition, the Systemising Man-Made Objects template that the students had used in previous years was also provided to the participants as a design guide for this design challenge (see Table 1).
The content of the design brief for Study 1 was based on authentic design challenges used in the Technology high school classroom. Participants were advised that they were free to apply any design, making and problem-solving strategies that they felt appropriate in order to complete the design challenge successfully within the one hour timeframe.

4.10 Study 2 - The Brisbane Library Design Brief

Design Brief

The Brisbane Library needs to move all of the books from the old town library to the new town library. However, the library only has a budget of $50,000 to move the books and all of the estimates from the Removalist companies far exceed the library’s budget. Your challenge is to design a way of moving all of the libraries books for $50,000.

Two ASIT conditions exist for creative solutions:
- Closed World condition (suggest illustration)
- Qualitative Change condition (ditto)

The Closed World condition requires that NO NEW TYPES of objects may be introduced into the solution

Qualitative Change condition examines changing the RELATIONSHIP between an undesired effect and the cause of that effect (Worsening Factor)

Simple Problem Statement:

“We don’t have enough money to move all our books”

Note: There is nothing creative about our problem statement

Simple Solution Statement:

“To move the books”

Note: There is nothing creative about our solution statement

List all objects in the Problem World (NB: This is a process the participants in the study were familiar with)

Problem Objects -


86
Environment Objects

List all objects in the Solution World

Problem Objects:

- Books
- Budget
- Movers
- Library
- Distance to New Library

Environment Objects

Note: The Closed World requires that the Problem World and Solution World objects are the same types

Sample List of objects for Library case study

Problem Objects:

- Books
- Budget
- Movers
- Library
- Distance to New Library

Environment Objects:
• Book Borrowers
• Library Staff
• Other people
• Streets
• Other vehicles on the streets

The whole idea of ASIT is that the method forces us to check all the solution directions we would probably not consider without the method.

Which ASIT tool will you use to solve this ASIT problem?

- The Unification Tool
- Unless you have it elsewhere you need a brief description of each of these
- The Multiplication Tool
- The Division Tool
- The Breaking Symmetry Tool
- The Object Removal Tool

You have 1 hour to complete the design challenge.

The author developed this ASIT design brief from material contained in an Introduction to ASIT (Horowitz, 2001). The ASIT design brief above included brief explanations and user tips that highlighted the meaning of each ASIT condition, such as: The Closed World condition requires that no new types of objects may be introduced into the solution. Participants were also given an ASIT booklet that outlined all of the ASIT Rules, sometimes known as ASIT Tools, and procedures to assist them when working on the design challenge. The ASIT problems solving strategy is a process the participants in the study were familiar with. The ASIT Rules and tools are summarised below:

**Closed world:** The Closed World condition requires that no new types of objects may be introduced into the solution.

**Qualitative Change:** Qualitative Change condition examines changing the relationship between an undesired effect and the cause of that effect (Worsening Factor).

**Problem World:** a collection of objects that are in the problem arena. These objects can be divided up into two groups including:
1. Problem Objects: the objects that create the problem;  
2. Environmental Objects: objects that are in the problem arena but that don’t contribute to the problem and/or are not affected by it.

*Division Rule*: Solve a problem by dividing an object and reorganizing it parts. The following is a summary of the main stages involved in using the Division rule:

1. Define the problem world;  
2. Choose an object (make a list of the parts or sub-objects);  
3. Elaborate the solution.

*Breaking Symmetry Rule*: Solve a problem by turning a symmetrical situation into an asymmetrical one. The following is a summary of the main stages involved in using the Breaking Symmetry rule:

1. Define the problem world;  
2. Break the symmetry;  
3. Process the solution.

*Multiplication Rule*: Solve a problem by introducing a slightly modified version of an existing object into the current system. The following is a summary of the main stages involved in using the Multiplication rule:

1. Define the problem world;  
2. Define the wanted action;  
3. Do the multiplication;  
4. Elaborate the idea and develop the solution.

*Unification Rule*: With the Unification tool we use an existing object from the problem world to do the action. The following is a summary of the main stages involved in using the Unification rule:

1. Define the problem world;  
2. Determine the wanted action;  
3. Make the Unification (between and object and a new function);  
4. Develop and elaborate the idea.

The participants chosen for Study 2 in 2010 were from the same group as those in Study 1; however, there was a significant difference in the manner in which the design challenge for Study 2 was to be solved, as Study 2 was to be solved using only the ASIT problem-solving process. To support the participants’ problem-solving efforts
they were encouraged to record each of the response in the designated areas of the ASIT worksheet.

4.11 Data Collection

Prior to the commencement of each design challenge the participants were each given a design brief for the problem they were about to solve which was then discussed for five minutes with the group. The design brief specified that participants were to work on the design challenge individually. Each of the three participants was assigned a dedicated research assistant who monitored each participant’s activities and performances during the Studies. The participants were not familiar with their allocated research assistant for the Studies. The research assistants were given a ten-minute briefing on their role and procedures during the Studies. The responsibility of the research assistant was to prompt the participants to continue to verbalise their thoughts and actions while engaging in the problem-solving process. This action was taken by the research assistants if the participants stopped verbalising for more than ten seconds. This was in accord with standard protocol analysis procedures (Ericsson and Simon, 1993). In addition, an independent Study supervisor was present in the room to oversee the running of both Studies and to discuss any questions that may arise either from the students or their research assistants. The Study supervisor was known to the participants; however, he had not been involved in teaching the participants during the course of their degree program. Prior to the commencement of the event the study supervisor was given a ten-minute briefing on the procedure for the data collection and the content of the design briefs. The author of this thesis did not act as a research assistant or supervisor for either Study.

Data collected included design challenges, artefacts, video footage and audio soundtracks of participants’ activities and design solutions. In addition, hardcopies of sketches of design-based, technological solutions were also collected and analysed to provide imaginal data to assist in interpreting verbal data. Each design challenge was conducted over a 60-minute period with a scheduled five-minute, rest break in proceedings between the two case studies. The participants were advised that they did not have to use the total 60-minutes to complete each design challenge. In addition, if the participants completed a design challenge prior to the 60-minute time frame they
asked to remain in their seat until all participants had completed the challenge. The studies took place on Tuesday 21st of September, 2010. The data collection activities were consistent with activities participants would engage with during their program. Each participant attempted to solve two technological problems. The first problem was solved with participants having a free choice of problem-solving strategy and the second using the ASIT problem-solving process. Verbal protocol processes were used where participants were asked to verbalise whatever thoughts came into their minds as they engaged in the problem-solving. These were recorded and provided the basis for this section of the study and the findings reported in Chapters 5 and 6.

4.12 Data Preparation

Audio recordings from each problem-solving episode were transcribed and segmented into sections that represented the smallest unit of meaning as the first stage in preparation for analysis. Segments were then coded in terms of how participants used their procedural knowledge. This was classified in terms of Generation, Exploration and Executive Control procedures. After coding, the episodes were divided into equal tentiles. Tentiles were created by dividing the total activity time into ten equal segments, by time. In the transcripts and extracts from the transcripts each segment is numbered in the following manner: T3 09:10. In this example the ‘T3’ represents Tentile number three and the number 09:10 represents the end of the segment period in time, nine minutes and ten seconds. At the completion of the coding process the participant’s data was presented in the form of a scatter-plot.

One aim in doing this was to allow the activity to be compared across participants and between the free problem-solving process and the ASIT problem-solving process. In addition, dividing the protocols into ten equal tentiles also highlighted the differences in the time taken by each of the participants to solve the same problem. During Study 1 and 2, the tentiles and segments that best illustrated the deployment of cognitive procedures and that highlighted participants’ problem-solving processes were discussed in the analysis in Chapters 5 and 6. The study employed a cognitive psychological approach (Anderson, 1993) to the analysis of problem-solving behaviour. A sample of a verbal protocol prior to coding is shown below in Table 2:
Table 2 Example of the Initial Representation of Problem Solving Data Pre-coding

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>ummm …</td>
</tr>
<tr>
<td>2.</td>
<td>I am just going to write down the tool types so that I can sort of remember them easier</td>
</tr>
<tr>
<td>3.</td>
<td>so what I have put down here</td>
</tr>
<tr>
<td>4.</td>
<td>ummm …</td>
</tr>
<tr>
<td>5.</td>
<td>I am just planning out each of the tools</td>
</tr>
<tr>
<td>6.</td>
<td>Ummm …</td>
</tr>
<tr>
<td>7.</td>
<td>The example that was used with them … each time</td>
</tr>
<tr>
<td>8.</td>
<td>so that will probably just jog my memory cause…</td>
</tr>
<tr>
<td>9.</td>
<td>I think we have done most of them</td>
</tr>
<tr>
<td>10.</td>
<td>Ummm… and with each there is the general…</td>
</tr>
<tr>
<td>11.</td>
<td>In each of them you identify the problem world, the wanted action then you insert the tool out of the list and then you develop the idea</td>
</tr>
<tr>
<td>12.</td>
<td>Ummm…</td>
</tr>
<tr>
<td>13.</td>
<td>So I am just going through ummm…</td>
</tr>
</tbody>
</table>

The audio track from the videotape data was converted to the format illustrated above in Table 2. The videotape data was retained in order to verify coding decisions and to clarify non-verbal information such as hand gestures and pauses that could not be coded and represented in the transcribed data.

4.13 Data Analysis

The following section presents the model used to code the verbal protocols for Studies 1 and 2. This model was derived from that established by Middleton (1998). The data from the two studies was analysed to establish firstly, the cognitive procedures employed by pre-service Technology teachers when solving complex technological problems and, secondly, the problem-solving strategies they utilised to solve technological problems was examined. In addition, the differences across problem-solvers of different degrees of expertise, including the time taken to solve a problem and the cognitive procedures deployed during the problem-solving activity were also analysed across participants.
4.14 Verbal Protocols

The think-aloud method, known as protocol or verbal protocol analysis (Ericsson and Simon, 1993), is the process where participants describe their cognitive activities in a continuous manner whilst performing a task. However, no attempt to analyse the participants thoughts, whilst engaged in the performance, is made by either the participants or the researcher. Ericsson and Simon (1980) argue that if information is verbalised at the time the participant is attending to a task the procedure is considered a concurrent verbalisation (Ericsson and Simon, 1980, 218). In contrast, if the participant is asked about cognitive processes that occurred at a previous time it is considered to be a retrospective verbalisation procedure (Ericsson and Simon, 1980, 218). As the researcher in this study was interested in the overt behaviour of the participants during the design challenge, the employment of concurrent verbal protocols was deemed appropriate.

It is argued that verbal protocols allow the researcher to access otherwise difficult or unobtainable information about task-specific and more general metacognitive knowledge and behaviours including perception, ideas, feeling and motives. However, these verbal protocols are not seen as thought processes directly but rather inputs and outputs of short-term memory (Ericsson and Simon, 1993) that provide indications of cognitive activity.

Rowe (1991) identified a number of possible limitations of the think-aloud protocol. These included: (a) inadvertent verbal or non-verbal cueing by the researcher, (b) verbal ability, and (c) access to conscious processes. Rowe argued that inadvertent verbal or non-verbal cueing by the researcher will directly affect the course of problem-solving and therefore alter the outcome of the study. Verbal ability in this context relates to the participants thinking or language skills and their ability to verbalise the cognitive processes. Poor thinking or language skills may result in a poor protocol. Finally, Rowe notes that participants are only able to verbalise conscious processes and any process that has become automated is not able to be verbalised. The first two of these limitations has been dealt with in detail in 4.5, Selection of Participants.
Rowe (1985) states that participants need to feel comfortable with the think-aloud process which in turn will minimise the frequency of any interference by the researcher whilst they are performing the task. For this reason participant selection in the context of this study was an important factor and as a result participants were chosen who stated that they felt comfortable verbally expressing their thoughts and actions while being recorded. Ericsson and Simon (1993) argue that if this was not the case, that the effort of verbalising would change the nature of the verbalisations, negatively affecting its quality.

The final limitation, that of being able to access conscious process and not those that have become automated, is dealt with in the plan of the design challenge. As it was the goal of the research to study only the non-automated responses of the participants the design challenges were intentionally created to be complex and difficult to solve. As a result the ability of the participants to solve the design challenges using tacit knowledge or automated processes was limited. Therefore, the inability of the study to analyse the tacit knowledge or automated process of the participants responses was not considered a threat to the validity or reliability of the study.

A further potential limitation of the think-aloud protocol was the possibility that the researcher and raters may code the verbalisations incorrectly as a result of their prior knowledge of the coding categories. Ericsson and Simon argue that this may occur unintentionally if the researcher or rater applies their own knowledge in making coding decisions. However, the question of rater bias is addressed in the studies reported in this thesis through the introduction of multiple coding raters. In addition, independent raters were utilised to check the coding process. The coding process is discussed in 4.15.

4.15 Coding Framework

The following section presents the coding model used to code the verbal protocols for Studies 1 and 2. This model was derived from that established by Middleton (1998). The framework of the Middleton cognitive procedural model draws on the Generation and Exploration theories of Darke, (1979); Finke, Ward and Smith, (1992); Hillier, Musgrove and O’Sullivan, (1972), with both of these operating under the Executive
Control procedures of Stevenson, (1991). Generation procedures are those involved with the generation or creation of a solution or solutions. Exploration procedures involve the exploration of a problem context and constraints as well as the various attributes and elements of those constraints. Exploration procedures also include the investigation of possible solutions or solution elements. Executive Control procedures are concerned with the process of planning, monitoring and evaluating what to do and when to do it. The cognitive problem-solving theory of the authors mentioned above is further explained in Chapter 2. The Middleton (1998) model enabled the verbalised segments of the participants’ transcripts to be interpreted in terms of their cognitive procedure. Importantly, the Middleton model allowed conclusions regarding the participants’ problem-solving behaviour to be drawn.

The verbal protocols of each problem-solving activity were segmented into the smallest unit of meaning after which they were coded into one of ten types of Cognitive Procedures. These ten Cognitive procedures were located within the three overall categories of cognitive procedure including: Exploration, Executive Control and Generation (Table 3).

### Table 3 Categories of Cognitive Procedure

<table>
<thead>
<tr>
<th>Category of procedure</th>
<th>Exploration procedures</th>
<th>Executive Control procedures</th>
<th>Generation procedures</th>
</tr>
</thead>
</table>

#### 4.16 Exploration Procedures

Exploration procedures refer to the exploration of problem constraints and attributes as well as the various attributes and elements of those constraints. Exploration procedures also include the investigation of possible solutions or solution elements.
These procedures have been identified by Finke, Ward and Smith (1992), Gross and Fleisher (1984), and Simon and Barenfield (1969). Each is defined in turn below.

4.16.1 Exploring Constraints [EC]
Exploring Constraints [EC] identifies aspects of the problem context or design proposals as containing elements that are perceived as adding to the complexity of the problem. (Described also as acknowledging constraints (Finke, Ward and Smith, 1992; Gross and Fleisher, 1984; Simon and Barenfield, 1969). For example: *so with the inclusions I can only use what's available* or: *no new types of objects can be added*. These verbalisations are relating to the constraints of the ASIT Closed World rule. Constraint exploration may be preceded or followed by evaluative verbalisations. In some instances the evaluative comment is necessary to establish that an utterance is indicating a constraint rather than an attribute.

4.16.2 Exploring Attributes [EA]
Exploring Attributes [EA] is the exploration of aspects of the problem context or proposed solutions that either facilitate problem resolution or define problem context (Finke, Ward and Smith, 1992). Listing all objects in the problem would be an example of the Exploring Attributes of the problem, for example: *book borrowers, library staff, other people, streets and other vehicles on the streets*. Both exploring attributes and exploring constraints are processes of establishing the properties of the givens of a problem or of proposed moves. Whether an individual designer regards a particular property as a constraint or attribute may vary depending on the context and the level of expertise.

4.17 Executive Control Procedures
The category of procedures referred to as Executive Control contains the procedures of Goal Setting, Strategy Formulation, Goal Switching, Monitoring and Evaluation. The procedures of Executive Control have been identified by a variety of researchers, including Anderson (1993), Scandura (1981), Chan (1990), Gott (1989), Simon (1981) and Perkins (1990). Each is defined in turn below. Executive Control
procedures are concerned with the process of planning, monitoring and evaluating what to do and when to do it.

4.17.1 **Goal Setting [GS]**

Goal Setting [GS] is establishing an overall goal and is expressed in terms of the establishment of general principles such as: *the Brisbane library needs to move all of its books from the old town library to the new town library* or: *we need to achieve a concertina effect in here to achieve ...*

4.17.2 **Strategy Formulation [SF]**

Strategy Formulation [SF] is an indication of a general heuristic for approaching a problem or parts of a problem (Schön, 1990), for example: *all right so this is just writing down all the elements of a lightbulb and its packaging* or: *so I guess we just look at a couple of lampshades.*

4.17.3 **Goal Switching [SW]**

Goal Switching [SW] is a change of attention from one aspect of the problem to another (Eckersley, 1988). Goal switching is often established by the presence of a significant pause bounded by two verbalisations that are not directly related to one another. An example of switching is: *now that I have made some early ideation let's go through and have a look at our physical ... or: so now I think I will go for this one because it wants to be the best ... right so ... I am going to need a bit more material because I've got some basic shapes and I need to test ...* It can otherwise be indicated by change of focus of attention.

4.17.4 **Monitoring [MO]**

Monitoring [MO] is the process of checking the progress of problem-solving to establish if goals are being achieved and solution constraints satisfied (Chan, 1990; Simon, 1975). For example: *One, Two, three, four, five ... so in reference to ... four (number of solutions drawn on the page) or: so working through this ... are examples*
of a section of a protocol indicating a monitoring process. Monitoring statements are sometimes followed by evaluation statements.

### 4.17.5 Evaluation [EV]

Evaluation [EV] is the normative statements about proposals, attributes or strategies (Finke, Ward and Smith, 1992), for example: *that could be quite funky but it wouldn't actually work as a ... or: that's a good idea I just thought of.* Evaluative statements are sometimes preceded by monitoring statements.

### 4.18 Generation Procedures

The generation category refers to the procedures of Retrieval, Synthesis and Transformation. These procedures are those involved with the generation or creation of a solution or solutions and have been identified by Finke (1989), Larkin and Simon (1987), and Weber, Moder and Solie (1990). Each is defined in turn below.

#### 4.18.1 Retrieval [RE]

Retrieval [RE] is the retrieval of knowledge from long-term memory (Finke, 1989), or the retrieval of information from visual perception of physical objects or visual displays (Larkin and Simon, 1987). Retrieval verbalisations are most easily recognised when they are referring to learned rules or strategies. For example: *I've got a gut feeling if I can remember it correctly that it will be something along the lines of ... is an example of retrieval.* Retrieval procedures are often employed as part of the synthesis or transformation process. That is, when a problem-solver synthesises a solution by combining two existing ideas, the existing ideas are retrieved from either the external world or from memory. Verbalisations are coded as Retrieval [RE] only if it is clear that no synthesis process has already taken place.

#### 4.18.2 Synthesis [SY]

Synthesis is the formulation and articulation of a specific proposal to solve a problem or sub-problem (Finke, 1989). For example: *so what I am doing ... is just putting the folds together ... on the lampshade* is a response to the identified need to provide a
lampshade, the designer retrieves schemas associated with “nets/templates”, in
general and schemas associated with the constraints and possibilities for the particular
lampshade in question. From these retrieved schemas, a specific proposal for a
lampshade is synthesised. Thus synthesis involves the bringing together of
information to create a new element.

4.18.3 **Transformation [TR]**

Transformation [TR] is the modification of a proposed idea to enable it to solve a
particular problem (Weber, Moder and Solie, 1990). Changing the dimensions of one
element to accommodate another or modifying a structural feature to allow it to serve
two purposes are examples of transformations: … *going with the first... umm*
*design, the cone shape, that can be fairly easily replicated into packaging* is an
example of a transformation.

Table 4 shows the same portion of verbal protocol Segments as Table 2 after the
application of the coding process.

**Table 4 Example of the Initial Representation of Problem Solving Data Post-
coding**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>ummm … [?]</td>
</tr>
<tr>
<td>2.</td>
<td>I am just going to write down the tool types so that I can sort of remember them easier [SF]</td>
</tr>
<tr>
<td>3.</td>
<td>so what I have put down here [MO]</td>
</tr>
<tr>
<td>4.</td>
<td>ummm … [?]</td>
</tr>
<tr>
<td>5.</td>
<td>I am just planning out each of the tools [SF]</td>
</tr>
<tr>
<td>6.</td>
<td>Ummm … [?]</td>
</tr>
<tr>
<td>7.</td>
<td>The example that was used with them … each time [MO]</td>
</tr>
<tr>
<td>8.</td>
<td>so that will probably just jog my memory cause… [MO]</td>
</tr>
<tr>
<td>9.</td>
<td>I think we have done most of them [MO]</td>
</tr>
<tr>
<td>10.</td>
<td>Ummm … and with each there is the general… [MO]</td>
</tr>
<tr>
<td>11.</td>
<td>In each of them you identify the problem world, the wanted action then you insert the tool out of the list and then you develop the idea [EC]</td>
</tr>
<tr>
<td>12.</td>
<td>Ummm … [?]</td>
</tr>
<tr>
<td>13.</td>
<td>So I am just going through ummm… [SF]</td>
</tr>
</tbody>
</table>
It can be seen in Table 4 that in this section of data, Participant B verbalised 13 segments that indicated the deployment of the following procedures:

**T1 00:00**

- **Generation**: Retrieval [RE] - 0, Synthesis [SY] - 0, Transformation [TR] - 0,
- **Exploration**: Exploring Constraints [EC] - 1, Exploring Attributes [EA] - 0,

### 4.19 Representing Data in Scatter-plots

In order to represent the coded data on a scatter-plot, each performance was divided into ten equal portions by time, called Tentiles. This then provided descriptive statistics that could be used to construct scatter-plots of each participant’s problem-solving activity as illustrated in Figure 11. Scatter-plots were chosen to represent the data collected as they allowed the data to be presented in such a way that the type and number of procedures could be seen graphically for every Tentile of the problems solving activity. In addition, the scatter-plot also allowed comparisons to be made of the procedure types within each Tentile across participants and across studies. In Figure 11 the scatter-plot representing the data collected in Table 4 can be seen.

**Figure 11 Example of a Participants Scatter-plot**

![Participant G Study 1 Scatter-plot](image)
The ‘Tentile’ numbers on the ‘X’ axis in the scatter-plot represents the end of each Segment period in time while the ‘Procedure by Category’ on the ‘Y’ axis represents the maximum number of procedures deployed by the participant. These numbers and intervals vary across participants depending on the number of procedures deployed and the length of time the participant took to complete each of the design challenges.

4.20 Uncoded Segments

The design challenges in Studies 1 and 2 were designed to be complex and difficult to solve, therefore limiting the participants use of tacit or automated knowledge. However, when transcribing the audio soundtracks of the verbal protocol a significant number of non-verbalised intervals such as: ... (pause) and verbalisations such as; sigh, okay and ummm were recorded during the design challenges. Johnson (1964) found similar patterns of delay and argues that participants pause during verbalisations when they experience difficulties in solving a problem.

Due to the ambiguity of the intended meaning of these verbalisations and pauses they were not coded in the transcript or included in the final data; however, they are represented in the transcripts by the following - [?]. These verbalisations are; however, important as they contribute to the overall analysis and interpretation of the data. An example of these types of verbalisations can be seen below in T3 09:10:

T3 09:10

1. you've got [?]
2. ummm ... [?]
3. ummm [?]
4. let's say [?]
5. phew [?]
cognitive process and claim that in order to obey the think-aloud instructions the participants, at the expense of slowing down their performance of the task, may take time to translate their inputs and outputs into verbal form.

Despite the slowing or possible incompleteness of the verbalisations Ericsson and Simon (1980) maintain that the direction and structure of the task-performance will remain largely unchanged. However, on some occasions during the verbal protocols these pauses were followed by a change in direction in the participant’s problem-solving strategy. On these occasions the pauses in the problem-solving process were of note because they indicated a change in direction or strategy from those applied prior to the pause, as can be seen below in T5 18:20:

**T5 18:20**

6. So they all need to … so they all need to have that light somewhere
   [EA]

7. ummm … [SW]

8. So what's available? [EA]

In these instances the verbalisations were coded as Goal Switching (SW) and are represented in the scatter-plots under the category of Executive Control procedures.

### 4.21 Interpretation of Scatter-plots

The analysis of cognitive procedure deployment was combined with video, textual and sketching evidence to develop the overall findings and conclusions of both studies. This was achieved by undertaking a number of steps. Firstly, the cognitive category segments and associated video, textual and sketching evidence were referenced by the tentile number and time recorded in the transcript. Secondly, the segments were coded according to interpretation of coding procedures. Where there were anomalies or ambiguities as to the interpretation and coding of the verbalised segments, the segments were cross referenced with the video, textual and sketching evidence for clarification and interpretation. Thirdly, analysis was made of the coded segments for evidence of participants’ cognitive problem-solving procedures. For
example, evidence of the participants exploring the context and constraints of the design challenges was illustrated by the deployment of Exploration procedures, while participants experiencing difficulty whilst solving the design challenges verbalised certain Executive Control procedures, including switching, evaluation and monitoring procedures. Fourthly, the coded Segments were collated into overall procedural categories and entered into scatter-plots which enabled analysis to be made of the most frequently occurring categories of each cognitive procedure and their relationship to the levels of problem-solver as discussed in Chapter 2. The findings and conclusions of Studies 1 and 2 were then collated and analysed in Chapter 6 where comparisons were drawn between the results of both studies.

4.22 Ethical Clearance

Clearance to undertake the research was obtained from the Griffith University Human Research Ethics Committee (HREC). Griffith University approval reference number: EPS/58/07/HREC

4.23 Strengths and Limitations of the Research Design

In this section the strengths and limitations of the research design are outlined. The strengths of the research design can be summarised in terms of four features that relate to the data and setting. Firstly, the research design ensured that a rich data source was available and collected. Secondly, the data source included three types of data, visual protocols, verbal protocols and written accounts. The collection of three data sources made triangulation of coding possible. This triangulation enhanced internal validity. Thirdly, the method of data collection and analysis was transparent. Fourthly, the activities participants engaged in and the setting in which they engaged in the activities represented a high level of authenticity in terms of them resembling the activities they were intended to be researched.

4.23.1 Internal Validity

To strengthen internal validity it was important to ask two questions. Firstly, does the design of the intervention minimise compromises in drawing meaningful conclusions from the results and, secondly, is the study reporting on what it claims to be
reporting? In this section a description of the steps taken to strengthen the internal validity of the thesis is provided.

A number of potential threats to internal validity were recognised. The first of these was changing events over time. Creswell (2008) argues that internal validity can be threatened by history and that over time events may occur that impact on the internal validity of the study, such as additional conversations about the subject (in this case ASIT) or treatment of the content of lectures. In addition, Creswell notes that although in educational experiments it is impossible to control these events they can be minimised by the researcher. Minimising this threat to internal validity in Studies 1 and 2 was achieved by ensuring the group studied with the same tutorial and lecture content prior to the Study and with identical problem-solving activities during the study.

It was also recognised that participant selection may also impact on the internal validity of the studies (Creswell). It is argued by Creswell that inequities in the intelligence, background, age or gender of participants may threaten the internal validity of a study. In this thesis the threat to internal validity by the choice of participants was minimised by: selecting students who were full-time third year student teachers enrolled in the Bachelor of Technology Education (BTechEd); participants had been previously instructed in the ASIT problem-solving process and its application; participants had previous experience solving design and technological problems; participants were comfortable verbally expressing their thoughts and actions while being recorded; and participants agreed to take part in both studies.

The second issue recognised as threatening the internal validity of the studies is the question as to whether or not the study is reporting what it claims to be reporting? The degree to which this question threatens the internal validity of the studies is dependent upon the nature of the data collected and the intensity of focus of the investigation. To overcome this threat to the internal validity of the two studies reported in this thesis, the problem-solving performance of the participants was examined in its entirety. This was achieved through the collection of both visual and verbal protocols to produce what Simon and Kaplan (1998) describe as ‘rich data’. As a result it is argued that although decisions were made prior to the commencement of
the studies about what to investigate, the methodology used to collect the data ensured that important previously unidentified phenomena was not overlooked.

4.23.2 External Validity

External validity is concerned with … problems that threaten our ability to draw correct inferences [or generalisations] from the sample data to other persons, setting, and past and future situations (Creswell, 2008, 310). According to Cook and Campbell (1979) (in Creswell, 2008, 310) three threats may impact on the generalisation of data including Interaction of selection and treatment, Interaction of setting and treatment and Interaction of history and treatment (Cook and Campbell, 1979, in Creswell, 2008, 310).

Interaction of selection and treatment involves the inability to generalise beyond the groups in the experiment and as a result factors such as race, social, geographical, age, gender, or personality groups may impact on the external validity of the study. However, these factors were addressed by making the study as accessible and convenient as possible to the participants. The steps taken to minimise any threats to the external validity of Studies 1 and 2 included: the participants were selected from a group of student teachers enrolled in a third year Curriculum Development course; Studies 1 and 2 participant protocols were collected during a scheduled Curriculum Development class; Studies 1 and 2 were conducted in a quiet design-studio that was familiar to the participants. The design-studio was a setting where design and technology activities normally occurred and was adjacent to the main Curriculum Development class.

Interaction of setting and treatment is concerned with the inability to generalise from one setting to another, for example from a private school to a public school. This threat to validity was reduced by restricting Studies 1 and 2 to pre-service Technology teachers only, therefore no generalisation was made across settings as a result but rather only across participants and design challenges.

Interaction of history and treatment is concerned with generalising findings across past and future situations, for example, if the study had been implemented with one group at the beginning of the teaching semester and again with a different group at the
end of the teaching semester. Cook and Campbell (1979), (in Creswell, 2008, 310) argue that as a result the studies may not produce similar results. This threat to external validity was addressed by the following planning and action: performing the collection of data for all participants at the same date, time and location; all participants were provided with the same tuition prior to Study 1 and 2; and finally participants were supplied with identical design briefs, design materials, supporting documentation and the time allowed during the studies.

As a result of possible extraneous factors that may threaten the external validity of Studies 1 and 2 no claims are made that the results of the studies are generalisable. The conclusions drawn from the data collected highlights the type and variety of cognitive processes deployed by the participants during the studies. It is recognized that substantial further work would be required to verify the results more generally.

4.23.3 Reliability
Reliability can be divided into internal and external reliability. Internal reliability in this thesis was determined by the degree to which other researchers, using the theory and construct of the study, would achieve the same results. External reliability was determined by the extent to which an independent researcher, examining the same phenomena, would reveal the same constructs and results.

Maintaining the creditability of any study is important and one of the factors that affect the credibility of research is reliability. However, as Study 1 and 2 are largely qualitative in nature and rely on the views of participants, the collection of words and text and the analysis of these words for themes, the ability to replicate the studies exactly is considered low. Due to the nature of Studies 1 and 2 none of the problem-solving episodes could have been reproduced exactly; however, to reduce concerns regarding the reliability of Studies 1 and 2 a number of measures were taken. External reliability was addressed in Studies 1 and 2 by providing researchers seeking to undertake similar studies with detailed descriptions and comprehensive information relating to the settings, participants, procedures and methodologies of the studies. Internal reliability is dealt with in terms of coding reliability and is discussed in the following section.
4.23.4 Internal Reliability

Internal reliability is concerned with the extent to which the same results would be obtained by other researchers. This was addressed by establishing inter-coder reliability. A degree of coding reliability was achieved by providing samples of the verbal protocols of both studies to two independent raters. To code the samples of the verbal protocols each independent rater was supplied with a copy of the coding conventions outlined in 4.15 – 4.18. The coding conventions were discussed with the raters and a sample of each verbal protocol was coded with the rater and the researcher. After these discussions and a review of the coding conventions the raters independently coded a section of the verbal protocols. However, the coding by the independent raters highlighted the need to clarify the coding conventions as described in 4.14. As a result, the coding conventions of Middleton (1998) were reinterpreted to reflect the context of Studies 1 and 2 and the coding results by the researcher were re-examined and recoded.

At the completion of coding of all sample verbal protocols from Study 1, a review of those Segments where agreement was not reached between the researcher and the independent raters was undertaken. To resolve any discrepancies in the coding results a review of the information contained within the verbal protocols and the video recording was performed. As a result, a higher level of equivalence between the researcher’s and that of the independent raters was achieved. Rater 1 coded 210 Segments resulting in a measure of inter-coder reliability of 78% when compared with the researcher. Rater 2 coded 123 Segments achieving a measure of inter-coder reliability of 86% when compared with the researcher. After combining the results of Rater 1 and 2 and comparing this to the researcher an average percentage of agreement between the independent raters and the researcher was 82%.

Where agreement between raters was not achieved further examination of the visual protocols and the video recording data was performed. At the end of this review the conclusion was reached that the disparity in coding agreement between researchers and raters was due to the ambiguities in the semantic content of the protocols. This ambiguity led to different interpretations of meaning and therefore different
assignment of codes. Despite these differences and considering the nature of the design challenges the level of agreement achieved was considered acceptable.

4.23.5 Limitations
A potential limitation of the study was the use of a limited number of pre-service teachers as participants. Three participants were chosen out of a class of 14 students; however, while it may have been advantageous to have used more participants in the study, the three selected were chosen on the basis that they represented the variability of the class group in terms of age, experience and academic performance. In addition, should time have been available extending the study to include the technological problem-solving strategies of practicing high school teachers in a school environment, this may also have been advantageous. However, the intention was to gather in-depth material on the technological problem-solving processes of pre-service Technology teachers, so these potential limitations are regarded as posing no threat to the validity of the study. Several other issues seen as limitations to the study were also identified.

Finke (1989) argues that many forms of tacit knowledge can only be accessed via long-term memory with imagery processes and therefore do not potentially generate any verbal data. This limitation of verbal protocols to demonstrate tacit knowledge has been resolved in two ways: firstly by using a design challenge that was designed to be complex and difficult to solve by all participants it was envisaged that design solutions would not be obtained through access to significant tacit knowledge; and secondly it is argued that as tacit knowledge is not generally verbalised the use of visual as well a verbal protocols would increase the probability of any tacit knowledge that was used by the participants to be expressed in the form of sketches and notes and therefore captured on video and/or paper.

Thirdly, it is acknowledged that in order to perform the intervention the participants were removed from their normal classroom and moved to an adjacent design studio and that this may affect the degree to which the setting was authentic. However, every effort was made to make the problem-solving activity as normal as possible, and therefore an authentic component of the Curriculum Development course in which the participants were enrolled. In addition, the remaining students who were not chosen
for the research were undertaking identical design challenges and activities at the same time as those involved in Studies 1 and 2. Fourthly, the verbal protocol model of Ericsson and Simon (1980) predicts that if the participants are verbalising information that is already available to them, then thinking aloud will not change the course and structure of the cognitive process. Fifthly, although the coding of the verbal protocols displayed a consistent degree of equivalence between the researcher and the raters, complete agreement was not achieved. This was due in part to the ambiguous elements of the semantic content within the verbal protocols. However, despite the coding differences and the nature of the verbal protocols the level of agreement achieved was considered acceptable. Lastly, as stated earlier, no claims as to the generalisation of the results of the studies were made or inferred. However, there was no evidence to suggest that the participant activities in Studies 1 and 2 were systematically different from those undertaken by pre-service Technology teachers in general.

### 4.24 Conclusion

It is argued in this chapter that to analyse the complex processes people engage in when solving complex design based technological problems, a methodology is required that allows the analysis of a rich set of interconnected data from a relatively constrained number of participants. A number of methods for collecting and analysing data from a number of problem-solving activities is described and analysed in terms of their utility for analysing design based problem-solving.

It is also argued in this chapter that the strength of the research design is based on the use of design challenges and settings that have a high degree of authenticity, the richness and relevance of the data collected and the complementary nature of the visual and textual data. The use of a case study research method in Studies 1 and 2 also allowed the research to be directed by the theoretical framework established in Chapters 2 and 3 while allowing the data to influence the findings and thus identify issues not predicted prior to the event. Chapter 5 provides findings and detailed analyses from Study 1 while Chapter 6 provides findings and detailed analyses from Study 2.
CHAPTER 5

RESULTS AND ANALYSIS OF STUDY 1

5 INTRODUCTION

Study 1 investigated the manner in which pre-service Technology teachers solve technological problems. Study 1 focused on the problem-solving strategies of participants when solving a Sustainability and Packaging design brief. The Sustainability and Packaging design brief included several contradictory parameters which in turn revealed a number of undisclosed and conflicting design requirements. In addition, there were several additional features unique to Study 1. Firstly, Study 1 asked the participants to design and manufacture a tangible artefact, that of the packaging for a lightbulb that could then be transformed into a lampshade. A tangible artefact was not the outcome of Study 2. Secondly, participants were encouraged to solve the design brief with their choice of problem-solving strategy. However, it was requested that the participants did not apply the ASIT problem-solving strategy to Study 1 as ASIT was to be the subject of Study 2. The following sections present and analyse the results for the activities undertaken by the three participants in terms of their cognitive responses whilst undertaking the design challenges.

Three cognitive procedures were monitored during Study 1: Exploration, Executive Control and Generation. Exploration procedures are defined as involving the exploration of a problem context and constraints as well as the various attributes and elements of those constraints. Exploration procedures also include the investigation of possible solutions or solution elements. Executive Control procedures are concerned with the process of planning, monitoring and evaluating what to do and when to do it and finally, Generation procedures are those involved with the generation or creation of a solution or solutions to a problem.

5.1 Study 1 - Sustainability and Packaging Design

The following section presents and analyses the results for the three participants whilst undertaking the Sustainability and Packaging design challenge.
5.2 Participant B

Participant B was a 22-year-old male, third year student, and was a high school graduate when first enrolled in the BTechEd program as a student teacher. Participant B had no previous trade or technical training experience or qualifications. Participants were allowed 60 minutes to complete Study 1; however, Participant B completed Study 1 in 39 minutes and 55 seconds.

Study 1 was designed to be a problem-solving activity that was both difficult and complex to solve, as outlined in Chapter 4. It was also devised to ensure that participants were not able to solve the design challenge using automated procedures or tacit knowledge. The following section presents the interpretation of results for participant B whilst undertaking the problem-solving activity. The interpretation of participant B’s cognitive processes whilst completing Study 1 are illustrated Figure 12 in terms of Exploratory, Executive Control and Generative procedures.

Figure 12 Participant B’s Procedures whilst Completing Study 1

![Diagram of Procedures by Category]

5.2.1 Exploration Procedures

Exploration procedures involve the exploration of a problem context and constraints as well as the various positive and negative attributes and elements of those constraints. Exploration procedures also include the investigation of possible solutions
or solution elements. With these exploratory parameters in mind Participant B’s procedural scatter-plot illustrates significant exploratory deployment commencing at Tentile 1 and peaking at Tentile 3. However, this high level of Exploration procedures in the early stages of problem-solving is not sustained and declines sharply between Tentile 3 and Tentile 5. At Tentile 5 Exploration procedures climb again to a second but smaller peak at Tentile 6 which then plateaus at Tentile 7 before finally declining to zero at Tentile 10.

Of the 42 procedures deployed during Tentile 3, 19 of these were Exploration procedures or approximately 45% of all procedures deployed. The context in which these Exploration procedures were deployed was that of investigating the first half of the problem which was associated with the packaging of the lightbulb. During Tentile 3 Participant B devoted almost half of his cognitive procedures to investigating the lightbulb and its features. An example of this exploration can be seen in the Segments of T3 09:10 below:

**T3 09:10**

7. so we will just say less sophisticated internals [EA]
8. and I think also the … method of supplying power to it would have been made different [EA]
9. you wouldn't have that screw-bulb … I don't think [EA]
10. it would have been set up within the object I guess [EA]

In T3 09:10 above, Participant B can be seen exploring the attributes of lightbulbs and is questioning whether or not past lightbulbs included a thread to screw them in to a fixture. This exploration was in response to a hand-out ‘Systemising Man-Made Objects’ that had been given to the participants at the beginning of the Study and is discussed in detail in 4.7. The hand-out asked the participants to analyse and list the features of a man-made product in the Past, Present and Future, in this case a lightbulb.

During Tentile 3, Participant B also deployed 14 un-coded verbalisations and pauses resulting in the highest number of un-coded verbalisations of any Tentile of the study. These un-coded verbalisations are interpreted as indicating the Participant B was
finding the design challenge complex and difficult to solve and was not able to deploy any automated procedures or tacit knowledge at this stage of the design challenge. The largest cluster of these appeared towards the end of the Tentile, as can be seen in T3 09:10 below:

**T3 09:10**

33. you've got [?]
34. ummm … [?]
35. ummm [?]
36. let's say [?]
37. phew [?]
38. what do you call it? [RE]
39. Ummm [?]
40. sigh [SW]

These un-coded verbalisations took place at a time when Participant B was deliberating over the various attributes and features of a number of different types and styles of lightbulbs, evidenced from the video recording of this Segment. Segment 38 appears alone amidst a number of uncoded verbalisations yet the transcript and the video of Study 1 reveal that Segment 38 relates to verbalisations made earlier in the Tentile regarding the components and features of the various lightbulb types. For example, in Tentile 31 Participant B refers to lightbulbs with filaments requiring a vacuum to operate within and Segment 32 refers to Light Emitting Diodes (LED’s) having a longer operating life.

The second peak of Exploration procedures occurred during Tentile 6 and plateaued through to Tentile 7. At this stage of the design challenge Participant B had moved on from exploring the lightbulb in Tentile 3 to investigating the second part of the design challenge, the packaging component. In T6 22:15 below, Participant B can be seen exploring the attributes and benefits of using packaging as a lightshade:

**T6 22:15**

19. I think it would be the most transportable which would save [EA]
20. which would save a lot of the costs [EA]
21. you could stack more on the shelves [EA]
22. you could put more on the trucks [EA]
23. you could store them a lot easier [EA]
24. so that would possibly be [EA]
25. that would possibly be one of the most cost-effective ways instead of having it built in like this where [EA]

Tentile 7 on the other hand was predominantly associated with exploring the constraints of design and manufacturing of the packaging and lightshade as seen in T7 26:50 below:

**T7 26:50**

20. I haven't really talked about the stand or socket because that has to be like … [EC]
21. like the lampshade has to sit on the stand or the socket and so it's got to be uniform [EA]
22. so maybe including that in the product [EA]
23. but that's not really what they ask for [EC]
24. Right, well I am going to just start making one [GS]

However, the result of this investigation was not conclusive and as can be seen above Participant B decided to ... *just start making one*. These actions are interpreted as indicating that although Participant B had extensively explored the constraints and attributes of the problem and design solutions, during Tentile 6 and 7, he was not satisfied with the result. As a consequence Participant B abandoned this line of exploration and reverted to trial-and-error as an alternative strategy to solve the design challenge. From this point on in the design challenge Participant B’s deployment of Exploration procedures declined sharply until the final Tentile where no Exploration procedures were deployed.

Early in Study 1 Participant B deployed significant numbers of Exploration procedures, particularly in the early stages of solving the problem. This is interpreted a indicating that during these periods Participant B was searching for, identifying and prioritising the information contained within the design brief. This is interpreted as
indicating that Participant B was forming an understanding of the problem which is supported by the video evidence where Participant B can be seen making notes of his exploration which he also discusses in the transcript. The deployment of Exploration procedures in this manner is interpreted as indicating that Participant B was exhibiting expert-like problem-solving behaviour. In this case Participant B has searched along a productive path instead of unproductive path (Simon, 2001). This pattern of searching for, identifying and prioritising the information proved to be very rewarding for Participant B who as a result, designed and manufactured a plausible solution to the problem.

5.2.2 Executive Control Procedures

Executive Control procedures are concerned with the process of planning, monitoring and evaluating what to do and when to do it. Figure 12 illustrates two major and two minor peaks of Executive Control procedures being deployed. The first of these major peaks commenced at the outset of the design challenge between Tentile 1 and Tentile 2. During this period Participant B was predominantly Monitoring [MO], Evaluating [EV] and Goal setting [GS] as seen below in T1 00:00:

T1 00:00

1. okay, so the next one is … [MO]
2. Okay, so this is … packaging [EC]
3. hey that's an idea [MO]
4. that's a good idea [EV]
5. that's a good idea I just thought of [EV]
6. ummm … so what have we got … [MO]
7. we've got the components of this design challenge are … [MO]
8. Okay [SW]
9. So … the challenge, the context is to illustrate the pros and cons … [GS]
10. I guess the design challenge, design the packaging [GS]
At Tentile 2 the deployment of Executive Control procedures began to decline with a smaller peak at Tentile 4 before continuing to decline through to Tentile 6. During this period of declining Executive Control activity Participant B was engaged in more Exploration procedures. This is interpreted as indicating that Exploration procedures deployed previously lead to continued Goal Setting [GS], monitoring [MO] and evaluating [EV] what to do and when to do it as can be seen below in T4 13:45:

T4 13:45

6. let's say that's that, all right [EV]
7. that's it, I need to design packaging [GS]
8. packaging must also be used as the lampshade [GS]
9. okay so [?]
10. okay so with packaging the … the main … the main concept behind it is it must be a lampshade [GS]

In T4 13:45 above Participant B can be seen deploying Goal Setting [GS] procedures. In this example Participant B has identified the main concept or final goal to be the lampshade and proceeds with the design of the packaging in mind. A third and larger peak of Executive Control procedures can be seen in Tentile 7 which also coincides with higher levels of Exploration procedures. However, the deployment of Executive Control procedures during Tentile 7 differed from those deployed in earlier Tentiles as Participant B was no longer in the process of exploring constraints of the problem but rather the attributes of design solutions he had generated. However, the Segments of Tentile 7 can not be viewed in isolation due to the content of the preceding Segments in Tentile 6. In T6 22:15 below Participant B can be seen exploring the sustainable validity of several of his design solutions:

T6 22:15

24. so that would possibly be [EA]
25. that would possibly be one of the most cost-effective ways instead of having it built in like this where [EA]
26. it's just you [SW]
27. you just fold it out and you screw it in [SY]
28. where you just take it out of the packaging there is less … there is less packaging in this one [EA]
29. but I think … [SW]
30. yeah [?]
31. the money spent on the packaging possibly save in the transport of the object because you can get so many more in [EA]
32. ummm … [?]

Participant B can be seen in T6 22:15 debating the impact of his design solutions on problem elements such as transport costs, the number of items you can fit in the transport vehicle and the cost-effectiveness of the product design. This is interpreted as indicating that Participant B was able to foresee the consequences of his design based on previous experience gained from solving problem types of a similar nature. Robertson (2001) argues that these traits are an indication that the problems solver is semantically rich as he is able to bring to bear a lot of experience of the problem type. This is also interpreted as indicating that Participant B is displaying expert-like behaviour.

Immediately following this deliberation, Participant B can be seen switching from one design to another, see T7 26:50 below:

**T7 26:50**

1. so that's one [MO]
2. so now onto two [SW]
3. so let's go back here [SW]
4. ummm … [?]
5. okay so let's look at this one [MO]
6. no because … [SW]

A review of the audio and video evidence in this instance reveals that Participant B had given each of the features of his design solutions a ‘weighting’ which was an indication of their impact on the sustainability of his design. The Goal Switching [GS] procedures deployed at this point are interpreted as indicating that Participant B was unable to make a final decision as to the importance of each of the features of his
designs and therefore was unable to choose a design to develop through to a final conclusion. This debate continued until Segment 24 of Tentile 7 where Participant B declared that: Right, well I am going to just start making one [GS] and then proceeded to manufacture his third design.

A further small peak of Executive Control procedures is evident in Tentile 10. However, prior to this point Participant B had solved the design challenge. Participant B’s cognitive procedures during this Tentile were interpreted as indicating that he was in the process of monitoring and evaluating his solution and his making skills. This process of deploying Executive Control procedures is evident when he makes statements such as: all right so far or so I guess that's the product that I want. Participant B concludes Tentile 10 by developing an evaluation sheet that illustrates how his design solution has ... addressed the challenge, what it looks like, what it will be doing.

In Study 1, Participant B can be seen to verbalise 92 Segments that are interpreted and coded as Executive Control procedures. This represents 44% of all coded Segments that Participant B deployed were concerned with the processes of Planning and setting goals and creating the steps needed to attain them, Monitoring the progress of this Planning and Evaluating and re-evaluating his mistakes, resources, strengths and weaknesses and what to do next and when to do it. Robertson (2001), Simon (2001) and Payne (2001) would argue that this behaviour is an indication that Participant B is expert-like in his problem-solving approach. However, given the high number of Executive Control procedures deployed while attempting to locate past knowledge or solutions rather than applying proven prior knowledge and schemas as demonstrated by expert-like problem-solvers, Goker (1997) would contend that Participant B was exhibiting novice-like problem-solver traits rather than expert problem-solving traits.

5.2.3 Generation Procedures

Generation procedures are those involved with the generation or creation of a solution or solutions. For Participant B, Generation procedures did not commence until Tentile 2. The scatter plot for Participant B illustrates two distinct peaks of Generation procedures, the first at Tentile 6 and a second peak with an identical level of activity
at Tentile 9. However, although there were two peaks in the deployment of Generation procedures they were both noted in the second half of the design challenge. During Tentile 6, which represented the first of the peaks, only seven Generation procedures were deployed. Although this appears to be a low number it was; however, the highest number of Generation procedures deployed of any tentile over the length of the design challenge.

The Generation procedures deployed during Tentile 6 are related to the design of Participant B’s packaging solution and its transition from packaging into a lightshade. For example, in Segment 10 of T6 22:15 below, Participant B can be seen to be Retrieving [RE] from memory indication of how similar his packaging and comparing this to packaging that is currently available. In Segments 14–16 of T6 22:15 below, Participant B can be seen deploying Synthesis [SY] procedures while formulating a specific proposal to solve the packaging problem:

**T6 22:15**

10. Similar to packaging that is used now [RE]
11. so that's there [?]
12. that's where the lampshade could be behind the object of the packaging [SY]
13. so … bulb [?]
14. so this could be the packaging for the bulb [SY]
15. so this keeps the sides up [SY]
16. packaging folds flat and out [SY]

The deployment of the Generation procedures for the lightshade is not dissimilar to those Generation procedures deployed for the packaging element of the design challenge in T9 35:20 as seen below:

**T9 35:20**

2. so what we are going to need is to that … fold … fold over [SY]
3. so will be the … two … inside the folding [SY]
4. like that … that can go over the top [SY]
Again in Segments 8, 16 and 17:

8. so what I am doing … is just putting the folds together …on the lampshade [SY]
16. I will just fold that again [SY]
17. which can be done if we … crease it here like that … that reduces the sides [SY]

Participant B’s deployment of Generation procedures is characterised by the deployment of 31 Generation procedures or approximately 15% of the total number of procedures coded. The deployment of Generation procedures started at a low level and produces two small peaks appearing at Tentile 6 and Tentile 9. However, after Tentile 9 the deployment Generation procedures steadily declined through to the end of the design challenge. Robertson (2001) argues that a problem-solver who lacks a depth of knowledge of a problem area or domain is semantically lean and therefore has little experience of the problem type. In this case the low number of Generation procedures deployed by Participant B during Study 1 is interpreted as supporting the argument of Robertson. As result Participant B was guided through the generation process by the deployment of Executive Control procedures.

5.2.4 Summary

Participant B deployed a considerable number of Exploration procedures in the early stages of Study 1; however, these high initial levels of Exploration procedures steadily declined through to the end of the design challenge. In addition, this exploratory activity coincided with slightly lower levels of Executive Control procedures being deployed during the design challenge. In contrast to the higher levels of Exploratory and Executive Control procedures deployed, Generation procedures built slowly from no activity at the beginning of the design challenge to a small peak in the early stages of the second half of the design challenge and a second small peak towards the end of the design challenge. However, overall the numbers of Generation procedures deployed during the study remained low.
Participant B’s low level of procedural deployment during the design challenge is interpreted as being indicative of a problem-solver who is experiencing difficulties solving the design challenge while experiencing a high cognitive load. In this case a high cognitive load is indicated both by the limited number of procedures deployed and by a significant number of non-verbalised actions such as; ... (pause), and verbalisations such as; sigh, okay and ummm during the design challenge. In addition, the combination of larger numbers of Executive Control procedures and the relationship between the Exploration, Executive Control and Generation procedures are interpreted as indicating that Participant B was attempting to solve the problems within Study 1 where no automated problem-solving procedures were available and trial-and-error was employed as a result. This is further indicated by Participant B announcing, after working on design four for some time, that it was crap and consequently switching to a new solution. In the absence of experience and automated procedures, Goker (1997) suggests that the problem-solver will view the design challenge as a problem rather than a task and as a result deductive or trial-and-error approaches will be applied to solve the problem.

It is argued that the low numbers of procedures deployed during Study 1 by Participant B are indicative of a problem-solver who is exhibiting semantically lean behaviour due to his lack of experience and knowledge of the problem type. Secondly, this semantically lean behaviour is interpreted as indicating that Participant B exhibited the traits of a novice-like problem-solver. In addition, Participant B’s Generation procedures are characterised by a small number of procedures deployed. This low level of deployment is further interpreted as indicating that Participant B lacked experience and knowledge of this problem type. Robertson (2001) considers that a problem-solver who demonstrates a lack of depth or experience in a problem type is semantically lean. As a result, it is argued that due to this apparent lack of experience Participant B was guided through the generation process by the deployment of Executive Control procedures.

During Study 1 Participant B displayed a combination of expert-like and novice-like problems solving characteristics. Participant B was able to interpret and prioritise the order in which to design and construct his solution to the design challenge and as a result completed the design challenge by generating a plausible solution to the design
brief. This is interpreted as indicating that Participant B was exhibiting expert-like problem-solving behaviour when operating within familiar problem-solving contexts. In contrast however, many of the problems and sub-problems that arose due to his design solutions resulted in the deployment of trial-and-error or novice-like cognitive behaviour. Therefore, it is argued that Participant B was an expert in the problem domain, in that he had prior knowledge and experience of the Technology context; however, the problem type presented Participant B with design conflicts that he was not familiar. As a result Participant B relied on novice-like problem-solving strategies such as trial-and-error and applied few automated procedures to resolve them. In addition, it is argued therefore, that Participant B did not perceive the design challenge of Study 1 as a task but rather as a problem.

5.3 Participant G

Participant G was a 28-year-old male, third year student, enrolled in the BTechEd student teacher program. Participant G had a formal trade qualification as an auto-mechanic.

Study 1 was intended to be a problem-solving activity that participants would find complex and difficult to solve. The deployments of Participant G’s procedures whilst completing Study 1 are illustrated graphically in Figure 13 and are discussed in the following section. Participants were allowed 60 minutes to complete Study 1; however, Participant G completed Study 1 in 37 minutes and 30 seconds.
5.3.1 Exploration Procedures

Exploration procedures involve the exploration of a problem context and constraints as well as the various positive and negative attributes and elements of those constraints. Three distinct peaks of Exploration procedures and a fourth smaller peak were deployed by Participant G while engaging in Study 1. However, these Exploration procedures were often separated by uncoded verbalisations, see T1 00:00 below:

T1 00:00

6. Label the parts that will assist it to carry out … [SF]
7. ummm [?]
8. LED, Diode [EA]
9. ummm [?]
10. ummm [?]
11. circuitry … [EA]
12. ummm … [?]
13. resister, resistor, power-supply same as current … [EA]
Initially Segments 8 and 11 appear unrelated in context to the previous Segments. However, closer examination of the transcript and video of Study 1 reveals that these verbalisations were not made in isolation but are a continuation of Segment 6 where Participant G is required to label the parts of the light that enable it to carry out its desired function. This line of enquiry continues in Segment 13. In Segment 8 Participant G identifies a particular type of light, that of the light emitting diode or LED, and then continues to explore the various components of the lighting system.

The first peaks of Exploration procedures occurred during Tentile 2 when Participant G was recorded exploring the constraints of the problem and the context in which the various elements occurred. For example, at the beginning of Tentile 2 Participant G can be seen to be exploring the context of the problem, as seen in T2 04:10 below:

**T2 04:10**

1. Students are provided with a selection of materials. Your design challenge is to design and make packaging for a light bulb that can be used as a lampshade, light shade for the same bulb. Students are provided with a selection of materials. [EC]

However, later in the Tentile he can be seen to be exploring the various attributes of a lampshade:

**T2 04:10**

15. lampshade is used to … ummm … channel light … [EA]
16. ummm [?]
17. while protecting …[SW]
18. while in a determined direction … [EA]
19. not sure why I'm writing in pink [?]
20. in a determined direction and prevent lights …[EA]
21. ummm … [?]
22. going in other directions or unwanted directions [EA]

This level of exploratory activity was not sustained; however, and declined sharply between Tentile 2 and Tentile 4. A second peak can be seen at Tentile 5 when
Participant G was exploring the attributes of the various solutions he had proposed to solve the design challenge, in this case the packaging of the lightbulb, see T5 16:40 below:

T5 16:40

18. the question is how would the packaging … [EA]
19. how would that packaging work safely if it was to be inserted [EA]
20. if it was to be a severe design [EA]
21. how would it fold? [EA]

After Tentile 5 the deployment of Exploration procedures again declined sharply resulting in no Exploration procedures being deployed during Tentile 6. However, a third peak of Exploration procedures is evident during Tentile 7. It is during Tentile 7 that Participant G deployed the highest number of Exploration procedures whilst engaging in the design challenge. In the following string of segments Participant G can be seen to be combining the attributes of both the packaging and the lampshade to create his final solution to the design problem, see T7 25:00 below:

T7 25:00

1. take our lightbulb package unit like so … [SY]
2. I will tag it where it is where the lightbulb is down as I can see how it slightly too small [EA]
3. ummm … [?] 
4. the idea being that is to come together … [EA]
5. that will need to go down like so [SY]
   i. (Interviewer asks ‘what are we trying to do here?’)
6. we are still trying to establish the net here to establish what shape we need to get [EA]
7. ummm … [?] 
8. a semicircle or a multisided polygon … [EA]
9. ummm … [?] 
10. to work as the … ummm … the light shade … [EA]
The above segments are interpreted as indicating that Participant G is applying expert-like problem-solving behaviour by creating and developing a number of cognitive artefacts or tools to assist him with resolving the problem including a net or template that included fixing tags. Participant G uses these tools to set-out the shape of the lampshade and uses the fixing tags to locate the correct position to attach each of the sections of the net. These actions are interpreted as indicating that Participant G has prior knowledge of these items, their purpose and the method for creating such a tool. Participant G also uses additional tools and techniques to create a solution, such as the use of semi-circular shapes and multisided polygons shapes to add dimension to the artefact he is sketching. Payne (2001) argues that cognitive artefacts or tools may improve the chances of a problem being resolved. They do not guarantee, however, that the solution will be successful. Closer examination of Participant G’s activities highlights the application of novice-like strategies such as trial-and-error (Goker, 1997) to determine which combination of these techniques may result in a successful resolution to the problem of designing and manufacturing the lampshade.

In the fourth and final peak, during Tentile 10, Participant G can be seen exploring the attributes of his solution, see T10 37:30 below:

**T10 37:30**

1. so … one thing I haven’t really taken into consideration here … errr … is the possible dangers associated with using a material such as paper around lighting [EA]
2. ummm … [?] 
3. it may be the fire danger that has been increased … [EA]

In T10 37:30 Participant G can be seen questioning the appropriateness of using paper to create a lampshade in this context. Drawing on prior knowledge he recalls the characteristics of paper and explores its suitability as an appropriate material to use in this context due to the potential fire danger associated with it. The connection that Participant G draws between the paper and its flammability is interpreted as indicating that at this stage of the design challenge the Participant G is deploying expert-like problem-solving behaviour by transferring knowledge from previous problem-solving events within a domain to a new problem type. Simon, (2001) argues that domain-
specific knowledge is the basis of expert skills as it connects problem-solving activity with memory.

5.3.2 Executive Control Procedures

Executive Control procedures are concerned with the process of planning, monitoring and evaluating what to do and when to do it. In Study 1 Participant G immediately commenced deploying Executive Control procedures resulting in the first of two larger peaks at Tentile 4 and Tentile 7 and a third but smaller peak in Tentile 10. An example of Participant G’s activity during Tentile 4, the first peak, can be seen below in the T4 12:30:

T4 12:30

12. so … if the box had maybe a hole in the lid the lampshade the … [SY]
13. little bit of ideation [SF]

The transcript and video evidence of the above segments illustrate that at this point in the design challenge Participant G was documenting and sketching his design solution. This activity continued throughout Tentile 4 and a further example can be seen below in T4 12:30:

T4 12:30

19. so I put direction just in a downward direction. [GS]
20. So if we were to go with something like that how would we then make that into a box? [MO]
21. Will go to a little bit of basic graphics here [SW]
22. the net for a box is something like that … [MO]

During Tentile 4 Participant G maintained deploying Executive Control procedures. This is interpreted as indicating that Participant G was actively engaged in the Executive Control process of planning and setting goals, monitoring, evaluating and re-evaluating his progress against these goals and deciding what to do next.
To a lesser extent the deployment of Executive Control procedures can be seen again in Tentile 7, the second of the larger peaks, where Participant G is in the process of planning and sketching his solutions to the problem of designing the lampshade. However, it is at this point that the extent to which Participant G applies trial-and-error strategies to solve the design problem can be seen below in T7 25:00:

**T7 25:00**

12. unfortunately … ummm … I am going to concede that that net has failed terribly and I need I go back to an idea that I just had which is to start with a square in the middle with said hole in it [EV]

Here Participant G concedes that his solution to the lampshade problem has failed and he needs to revert to a previous idea.

In Tentile 10 there is a small increase from Tentile 9 in Executive Control procedures; however, by this time in the activity Participant G has solved the design problem and is in the process of finalising, monitoring and evaluating his completed design rather than introducing any new elements to his solution.

During Study 1 Participant G can be seen deploying 105 Executive Control procedures or 53% of the total coded Segments. Executive Control procedures are concerned with the process of planning and setting goals and creating the steps needed to attain them, Monitoring the progress of this planning and evaluating and re-evaluating his mistakes, resources, strengths and weaknesses and what to do next and when to do it. The high level of Executive Control procedures deployed in this case are interpreted as indicating that Participant G is exhibiting novice-like problem-solving behaviour. During Study 1 Participant G can be seen deploying trial-and-error strategies to solve the problem. Goker (1997) would argue that the absence of automated problem-solving procedures indicates that the participant interprets the design challenge as a problem rather than a task, hence the application of the trial-and-error problem-solving approach. In addition, Goker states that this is the result of Participant G’s lack of experience with the problem type or problem. This interpretation also supports the argument of Robertson (2001) who suggests that if the
problem-solver does not know how to resolve a difficulty it can be considered a problem rather than a task.

5.3.3 Generation Procedures

Generation procedures are those involved with the generation or creation of a solution or solutions; however, Participant G did not commence the deployment of Generation procedures until Tentile 3 during this design challenge. After Tentile 3 Generation procedures steadily increased through to a peak which commenced at Tentile 4 and concluded at Tentile 6 before declining to zero at Tentile 8. Between Tentile 3 and Tentile 6 Participant G was involved the generation and creation of a number of solutions to the lampshade problem. Early in Tentile 4 Participant G was preoccupied with a design that would allow the lampshade to fit onto the lightbulb, as can be seen below in T4 12:30:

T4 12:30

1. with a hole punched in the middle it would be able to … [SY]
2. ummm … [?]
3. sorry … with a hole the screw base could fit through … [TR]
4. ummm … [?]
5. Which would when unfolded would provide a lampshade technique or a lampshade style [SY]

However, later in the Tentile his attention turned to refining this design and experimenting with ideas such as using a concertina effect on the sides of the lampshade, as can be seen in the following Segments of T4 12:30:

T4 12:30

29. this is testing my skill development here because I can't remember the net [RE]
30. I am thinking of the shade … [SF]
31. ummm … [?]
32. being … [?]
33. could also folded into a box [SY]
34. maybe concertaining … [SY]
35. err … [?]  
36. edges that fold with a flip lid that the user could cut off and discard [SY]

Experimenting with the design through trial-and-error dominated Participant G’s procedural deployment during Tentile 5; however, by Tentile 6 Participant G had turned his attention to the manufacturing of his design and its impact on the environment, as can be seen below in T6 20:50:

**T6 20:50**

25. less packaging equals err … greater value for money … [SY]
26. also hopefully with reduced impact on the environment [SY]
27. let's say something like that [SW]
28. taking into account the ideas of how this is going to fold up to become the packaging idea [SY]
29. so if we had something like that [SY]

The second and final peak of Generation procedures were deployed during Tentile 10 and were focused on the manufacture of Participant G’s solution to the packaging and lampshade problem. Below in T10 37:30, Participant G can again be seen refining his design solution as he was in the manufacturing process:

**T10 37:30**

8. a little bit of folding here and here [SY]
9. I really need to take into consideration the grain of the paper [SY]

In this case Participant G deployed 35 Generation procedures or 17% of the total number of procedures coded. Participant G’s deployment of Generation procedures is characterised by starting at a low level at a time when he was exploring the constraints and attributes of the problem. These procedures reached a peak in the middle of the Study, when he was generating ideas and solutions to the problem after which the deployment of Generation procedures declined. During the remaining of the Study, Participant G can be seen to be refining his design and making minor adjustments to
the end product. This suggests that Participant G did not have a vast store of ready-made solutions to the primary problem; however, he was able to overcome this deficiency by the deployment of Executive Control procedures to guide the generation process.

5.3.4 Summary

Participant G deployed a significant number of both Exploration and Executive Control procedures throughout Study 1; however, he did not deploy any Generation procedures until Tentile 3. From this point the number of Generation procedures steadily rose and peaked at Tentile 6 and again in Tentile 10. A decline in the deployment of Generation procedures was noted at Tentile 8 whereupon they declined to zero. This is interpreted as indicating that Participant G was not able to draw on a large store of solutions to the problem; however, he was able to compensate for his limited repertoire of solutions by deploying a significant number of Executive Control procedures to guide his activities.

These Generation procedures were complemented by similar patterns of Executive Control procedures; however, the deployment of Executive Control procedures does not appear to have prevented nor hindered the deployment of Generation procedures. This is interpreted as indicating that Participant G while creating a solution or solutions was also actively engaged in the process of planning, monitoring and evaluating what to do and when to do it.

This is not to say that Participant G did not experience some difficulties with developing a plausible solution to the problem. Participant G’s transcript highlighted a significant number of pauses and delays in the verbalisation of his thoughts; however, due to the ambiguous nature of these pauses and delays they were unable to be coded and are not included in the coded data. Johnson (1964) argues that problem-solvers pause or delay procedures during verbalisations when they experience periods of difficulty when engaged in a problem-solving activity. In addition, Participant G can be seen to develop a number of cognitive tools such as templates and nets to assist with the trial-and-error problem-solving process. Green (1989) maintains that the process of recording and transferring details of the problem or solution on external
artefacts such as paper indicates that the problem-solver is developing an information system. In the case of Participant G the information system that he developed enabled him to resolve a number of problems that were apparent in his design solution. Payne (2001) argues that the development of an information systems assists in the problem-solving process.

The number of Segments coded during Study 1 was a total of 197 and the number of un-coded Segments (including pauses and delays) was a total of 104, in all a total of 301 Segments were recorded. However, the un-coded Segments represent approximately 35% of the total verbalisations recorded during the design challenge. These pauses are interpreted as indicating that Participant G was finding the problem complex and difficult to solve and that he was attempting to solve the problem without automated problem-solving procedures being available to him. Goker (1997) argues that the problem-solver will resort to deductive or trial-and-error approaches when they perceive the design challenge to be a problem rather than a task when there are no automated problems solving procedures available to them.

5.4 Participant P

Participant P was a 34-year-old male, third year student, enrolled in the BTechEd student teacher program. He was a third year student with a formal trade qualification as a cabinet maker.

Study 1 was intended to be a problem-solving activity that participants found complex and difficult to resolve. The deployments of Participant P’s procedures whilst completing Study 1 are illustrated graphically in Figure 14 and are discussed in the following section. Participants were allowed 60 minutes to complete Study 1; however, Participant P completed Study 1 in 39 minutes and 06 seconds.

5.4.1 Exploration Procedures

Exploration procedures involve the exploration of a problem context and constraints as well as the various positive and negative attributes and elements of those constraints. In Figure 14 below, there are three distinct peaks of Exploration
procedures deployed during Study 1 these occur at Tentile 1, 5 and 9. However, the greatest numbers of Exploration procedures deployed during the design challenge appear early in Tentile 1. During the early stages of Tentile 1 Participant P devoted the majority of his effort towards unpacking and investigating the elements of the design challenge and the context in which they occurred.

**Figure 14 Participant P’s Procedures whilst Completing Study 1**

For example in T1 00:00 below, Participant P can be seen breaking down the design brief into its various elements:

**T1 00:00**

1. Your challenge is to design and make packaging for a light bulb that can also be used as the light shade/lamp shade for the same light bulb. [EC]
2. Inclusions [EC]
3. Students are provided with a selection of materials and asked to work on the design challenge individually (this is not a team challenge). [EC]
This line of enquiry switched at Segment 23 from exploring the constraints of the problem to exploring the attributes and inclusions of the various materials that could be used to produce a solution. In the excerpt below Participant P can be seen investigating the context of the design brief at Segment 23. At Segment 24 Participant P switches to the attributes of the inclusions and the conditions in which he is to produce a solution, see T1 00:00 below:

T1 00:00

23. that can also be used as a lampshade [EC]
24. right ummm … [SW]
25. bulb [EC]
26. ummm … [?]
27. size [EC]
28. materials used for making the box [EC]
29. ummm … [?]
30. ummm … [?]
31. … (long pause) [?]
32. Heat [EC]
33. insulation to prevent burning [EC]

In T1 00:00 Participant P can be seen to be exploring the factors involved when producing packaging and a lampshade from the same piece of material. Participant P investigates the bulb, its size, the materials that the box is to be made from and the potential dangers that could be present including heat and burning; however this excerpt also contains a number of uncoded verbalisations. Overall, during Tentile 1 Participant P expressed 25 uncoded verbalisations which represent the greatest number of uncoded verbalisations of the entire design challenge. These uncoded verbalisations are interpreted as illustrating that Participant P was finding the problem complex and difficult to solve.

From this point on the deployment of Exploration procedures steadily declined until Tentile 4 where the deployment of Exploration procedures again began to increase resulting in the second peak being produced at Tentile 5. However, during Tentile 5 Participant P continued exploring the attributes of the materials, the conditions in
which they would be used, and the solution that he had generated early in the design challenge, as seen below in T5 17:36:

**T5 17:36**

6. instead of ummm lost light ummm up onto the ceiling [EA]
7. that’s same possible design [EA]
8. ummm … [SW]
9. there could be a fire hazard there [EA]
10. ummm … [?]
11. ummm … right [?]
12. ummm … [?]
13. Right, how does … [EC]
14. the materials … size of the materials whilst constrained by the lightbulb [EA]
15. The materials from the box [EA]

Later in the T5 17:36 Participant P can be seen switching his attention away from the design process and begins to explore the implications of his design solution and its impact on sustainability, one of the conditions of the design brief, see T5 17:36 below:

**T5 17:36**

36. having the foil inside doesn't quite still make it sustainable and recyclable [EA]
37. so you won't be able to recycle the product as cleanly as you would if you only had cardboard [EA]

Moments later in T6 22:10 below, Participant P quickly justifies his decision to include aluminium foil in his design by declaring that it too is a recyclable material:

**T6 22:10**

1. Oh, foil is recyclable too isn't it? [EA]
2. So therefore, phew, look at that solved that one, recycled [EA]
Immediately following these statements in Segment 3 Participant P concluded that Solution 1 was now complete and began to explore a second solution to the problem. However, the deployment of Exploration procedures from this point steadily declined until Tentile 7 where no Exploration procedures were coded.

The deployment of Exploration procedures increased again resulting in a third and final small peak at Tentile 9 where only nine Exploration procedures were coded. However, unlike the two previous peaks of exploratory activity, the procedures deployed during Tentile 9 are predominantly concerned with refining the attributes of his final design and how his design solution might used be in a real situation, see T9 35:12 below:

**T9 35:12**

27. that base … could come as a package deal but then you are going to need an electrician to rewire it [EA]
28. ummm [SW]
29. so it needs to be a fit-on solution [SY]
30. ummm [SW]
31. you would only want to do it once [EA]

In T9 35:12 above, Participant P is investigating the prospects of manufacturing his solution as a package deal and the practicalities as to what this might mean for the purchaser or consumer. From this point on; however, the deployment of Exploration procedures continued to decline through to the end of the design challenge.

Exploration procedures involve the exploration of a problem context and constraints as well as the various attributes and elements of those constraints. In this case Participant P’s deployment of Exploration procedures are characterised commencing at a high level as he was investigating the constraints and attributes of the problem and problem elements. Directly after this high level of activity Participant P’s deployment of Exploration procedures steadily declined; however, two minor peaks were observed in the middle of the Study and again at the conclusion of the Study. This is interpreted as indicating that Participant P engaged in significant information
gathering activities at the outset of the design challenge and to a lesser degree for the remainder of the problem-solving process.

5.4.2 Executive Control Procedures

Executive Control procedures are concerned with the process of planning, monitoring and evaluating what to do and when to do it. During Study 1 a total of 120 segments of verbalisations were coded as Executive Control procedures. The deployment of these procedures resulted in two minor peaks and one major peak becoming evident in Participant P’s scatter-plot for Study 1. The first of the minor peaks occurred between Tentiles 3 and 4, a second at Tentile 6 and finally the largest of the peaks occurs at Tentile 8.

During the first of the minor peaks, Participant P can be seen deploying a variety of Executive Control procedures the majority of which are Goal Switching [SW] procedures. In total there were 12 Executive Control procedures deployed during the Tentile of which seven or approximately 58% were Goal Switching [SW] procedures. Goal Switching [SW] procedures indicate a change of attention from one aspect of the problem to another. During Tentiles 3 and 4, Participant P’s attention can clearly be seen to be switching and changing direction. For example in Tentile 3 Participant P switches from exploring the constraints of the environment in which the function of the object is carried out to Goal Setting [GS] and establishing the desired outcome of the design brief. However, between Segments 21 and 28 Participant P also verbalises a number of uncoded Segments as seen in T3 09:08 below:

**T3 09:08**

21. name the environment in which the function of the object is carried out [EC]
22. like that? [EV]
23. ok [SW]
24. that, that, that … [?]
25. ummm … [?]
26. ok [?]
27. so [?]
This switching of direction is interpreted as illustrating that Participant P was experiencing difficulty solving the problem and this pattern of redirection of attention continued in Tentile 4 as seen below in T4 13:02:

**T4 13:02**

1. This here ummm … prevents light from leaving the package [SY]
2. Ummm … [SW]
3. I think from memory there is one down in the bottom somewhere [RE]
4. Ummm … [SW]
5. There might be one on this side as well [EA]
6. something like that [EV]
7. phew … [?]
8. ummm … [?]
9. … (long pause) [?]
10. another possible box design [SW]

In this excerpt of Segments from T4 13:02, Participant P can be seen switching direction on three occasions and also verbalising a number of uncoded verbalisations. To code these segments and confirm their context required close comparison between the transcript, video evidence and the ideas Participant P expressed on his paper hardcopy.

Further, in Tentile 8 Participant P deployed 28 Executive Control procedures, of which 13 or approximately 46% were coded as Goal Switching [SW]. In T8 30:38 below, Participant P can be seen switching between his idea of folding out and opening up the lampshade when it is in the light fitting to managing the cardboard so that it does not get too close to the light bulb and get hot:
 Shortly after in T8 30:38, Participant P can be seen switching his attention between controlling the light direction of the second design solution to how the lampshade is screwed into the light fitting.

**T8 30:38**

26. the second solution for a spotlight doesn't have the solution for it to force the light to be directed down [EA]
27. ummm [?]  
28. so [SW]  
29. when that is screwed into the light fitting [EA]

During Study 1 Participant P deployed 120 Executive Control procedures of which 75 or approximately 63% were coded as Goal Switching [SW]. The combination of switching his attention between the various aspects of the problem and the verbalisation of uncoded segments is interpreted as indicating that Participant P found Study 1 complex and difficult to solve. However, Figure 14 highlights a close relationship between the deployment of both Executive Control and Generation procedures. This is interpreted as indicating that as a result of a limited depth to the solution available to Participant P, and the low levels of Generation procedures deployed as a result, that he was guiding the generation process with the deployment of Executive Control procedures. Robertson (2001) argues that due to Participant P’s lack of knowledge and or experience in this domain that he is semantically lean and therefore considered a novice problem-solver.

### 5.4.3 Generation Procedures

Generation procedures are those involved with the creation of a solution or solutions to a problem. During the course of Study 1, Participant P deployed a total of 67
Generation procedures. However, as can be seen in Figure 14, the greater portion of these procedures appears in the latter half of the design challenge.

Participant P produced only one major peak of Generation procedures during Tentile 7. After Tentile 7 the deployment of Generation procedures steadily declines towards Tentile 8 and then plateaus through to the end of the design challenge. Prior to Tentile 7 a gradual increase in the deployment Generation procedures from zero procedures deployed during Tentile 1 to a total of six procedures at Tentile 6 before rising to a peak at Tentile 7. However, the vast majority of these Generation procedures were coded as Synthesis [SY]. In this context Synthesis [SY] relates to the formulation and articulation of a specific proposal to solve a problem or sub-problem (Finke, 1989). For example, in T2 04:34 below Participant P can be seen implementing a strategy of recording data, this data will be used at a later time in the design process:

T2 04:34
1. … (long pause) [?]
2. (research assistant asks ‘what are you thinking now?’)
3. Oh, I am just getting a couple of measurements that will float around in the back, in the back [SY]

Later in T5 17:36, Participant P can be seen generating design ideas that will divert the light from being reflected off the ceiling of the room the lamp is used in.

T5 17:36
3. so we can possibly have a diffuser that can … stop light from coming up [SY]

However, in the latter stages of Tentile 6 Participant P’s attention switched from the design of the solution to the creation and manufacture of the solution out of the materials provided, this activity continued into Tentile 7. Below in T7 26:06, Participant P can be seen developing and applying cognitive artefacts such as collecting data, using templates, creating prototypes and working out how each of the components will be folded and manipulated. Zhang and Norman (1994) argue that by
transferring aspects of the problem to the physical environment makes problem-solving easier.

**T7 26:04**

1. ummm 220 by 90 [SY]
2. so that's the lightbulb we want to be able to protect the ends [SY]
3. so that's going to be … [SY]
4. what did I say, 220 [SY]
5. yeah, close enough [EV]
6. (as per the video there is a long pause as Participant P is drawing up his template so that he can make his design) [SY]
7. (research assistant asks ‘what are you thinking now?’)
8. Ahhh, this is going to be a semi-prototype for a spotlight [SY]
9. okay we need to fold it up and we will see how we can develop the actual packaging into a … [SY]

In total Participant P deployed 17 Synthesis [SY] procedures during Tentile 7, a trend which continued during Tentile 8 where 12 Generation procedures were deployed all of which were associated with the manufacture of the final solution to the design challenge. The Generation procedures that were deployed during Tentiles 9 and 10 were predominantly associated with the assembly of the final solution and further refinements and enhancements as can be seen below in T9 35:12:

**T9 35:12**

13. can come down on to the screw part [SY]
14. terminal in there [SY]
15. screw part goes in [SY]
16. ummm … [SW]
17. From here have … a… prong system [SY]
18. Just like coat hangers that can squeeze together to hold a packet in place [SY]

**T10 39:06**

17. and that stops the light from coming out [SY]
18. so you unwrap the light … and get it out [SY]
19. oh no the lamps too tight [EV]
20. ummm [SW]
21. now that shape needs to be evolved into … [SY]
22. the development of that will be … something like that [SY]
23. and currently my development of the same thing will be like that [SY]

In this case Participant P deployed 67 Generation procedures or 20% of the total number of procedures coded. Participant P’s deployment of Generation procedures is characterised by starting at a low level and coincided with a high number of Exploration procedures being deployed whilst exploring the constraints of the design challenge. This low level of deployment was maintained throughout the larger part of the Study with only one peak being documented at Tentile 7. After Tentile 7 the deployment of Generation procedures steadily declined through to the end of the design challenge. In the last stages of the Study, Participant P can be seen to be making minor manufacturing changes to the design. This suggests that although Participant P had generated a plausible solution to the design challenge that he did not have a great depth of ready made solutions to the primary problem and therefore Robertson (2001) would argue that the problems solver was Semantically Lean. At the conclusion of the Study 1, Participant P highlighted that his final product was a prototype and would require significant modification if it were to be manufactured on a larger scale.

5.4.4 Summary

Participant P deployed 330 coded procedures during Study 1. This number was made up of 143 Exploration, 120 Executive Control and 67 Generation procedures. However, during Study 1 the deployment of Generation procedures, and in particular Synthesis [SY] procedures, were consistently low even though a peak occurred during Tentile 7. In addition to the coded procedures there were 110 uncoded procedures deployed during the design challenge which represents approximately 33% of the total coded procedures deployed. These uncoded procedures are interpreted as indicating that Participant P found the design challenge in Study 1 complex and difficult to solve. This interpretation supports the findings of Johnson (1964) who argues that
when problem-solvers experience periods of difficulty when engaged in a problem-solving activity they pause or delay proceeding.

The combination of a significant number of Gaol Switching [SW] and uncoded procedures is interpreted as indicating that Participant P relied on trial-and-error strategies rather than automated procedures while attempting to solve the design challenge. Goker (1997) argues that when a problem-solver uses deductive or trial-and-error approaches that it is an indication that they perceive the design challenge to be a problem rather than a task. Goker also argues this cognitive phenomenon occurs when the problem-solver has no automated problems solving procedures available to them.

The comparatively high numbers of Exploration and Executive Control procedures and the relatively low numbers of Generation procedures are interpreted as indicating that Participant P experience and depth of knowledge and as a result was unable to draw on a large library of predetermined solutions. Robertson (2001) argues that a problem-solver who demonstrates a lack of depth or experience in a problem type is semantically lean and therefore considered a novice problem-solver. In addition, it is argued that Participant P compensated for his lack knowledge and experience of the problem type by guiding his problem-solving activities by deploying Executive Control procedures which helps him determine what needs to be done and when to do it.

Participant P also developed a number of cognitive tools such as sketches, prototypes and templates to assist with problem-solving and designing his solution to the design challenge. Green (1989) argues that the process of recording and transferring information and details of a problem or solution on external artefacts such as paper is an indication that the problem-solver is developing an information system that can be referred to at any time during the activity. Payne (2001) suggests that this strategy of transferring information to an external device or source assists in the problem-solving process. It is argued that this strategy assisted Participant P design and manufacture a plausible solution to the design problem.
5.5 Procedure Analysis across Participants - Study 1

The data collected during Study 1 included transcripts, video recordings, paper hardcopies of sketches and notes, and prototypes. Analysis of the data found that the participants spent a considerable amount of time at the start of design challenge interpreting and analysing the context and constraints prior to committing any ideas to paper. This is indicative behaviour of an expert problem-solver. However, the uncoded verbalisations and the pauses deployed during the design challenge, such as; ... (pause), sigh, okay and ummm were interpreted as indicating that the participants were unsure of how to proceed rather than indicating deep analysis of the problem. In order to compare the procedure deployment of participants during Study 1, the data were aggregated into Table 5:

Table 5 Procedure Analysis across Participants - Study 1

<table>
<thead>
<tr>
<th>Participants</th>
<th>Generation</th>
<th>Exploration</th>
<th>Executive Control</th>
<th>Total Coded Procedures</th>
<th>Total Uncoded Procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant B</td>
<td>31</td>
<td>87</td>
<td>92</td>
<td>210</td>
<td>57</td>
</tr>
<tr>
<td>Participant G</td>
<td>35</td>
<td>57</td>
<td>105</td>
<td>197</td>
<td>104</td>
</tr>
<tr>
<td>Participant P</td>
<td>67</td>
<td>143</td>
<td>120</td>
<td>330</td>
<td>110</td>
</tr>
</tbody>
</table>

The interpretation of the Table 5 is presented as follows. During Study 1, fewer Generation procedures were deployed by all participants over the length of the design challenge compared to either Exploration of Executive Control procedures. The high number and random manner in which Executive Control procedures were deployed and the low number of Generation procedures was interpreted as indicating that the participants were novice problem-solvers in this problem domain and as a result were trying to solve the design challenge when there were no automated problem-solving procedures available to them. The lack of automated problem-solving procedures led the participants to rely on trial-and-error strategies as their preferred strategy to solve
the design challenge. The participants verbalised their trial-and-error strategies in a number of ways; however, Participant B’s declaration whilst working on his fourth design for some time that it was *crap* [sic] and consequently switching to a new design solution was perhaps the clearest indication of the difficulties the participants were encountering and the unreliability of trial-and-error strategies.

The degree of problem-solving difficulty that the participants experienced was not the result expected for Study 1 as all the participants were thought to be experienced problem-solvers of this problem domain and type. This assumption was made as all of the participants over the course of their University program had been exposed to similar problems of this type in the Technology domain. This result may indicate some short-comings in the University program and the problem-solving strategies taught. However, despite the complex nature of the design challenge and the participants reliance on trial-and-error strategies, all participants successfully produced a plausible design solution to the design brief - Design and manufacture packaging for a lightbulb that can also be used as a lampshade.

5.6 Conclusion

The literature reveals a number of interpretations of the cognitive phenomenon referred to as problem-solving. This thesis examines student problem-solving in terms of the explanations of Bransford and Stein (1984), Deluca (1992), Payne (2001) and Green (1989). The interpretations of these researchers collectively address the manner in which problem-solvers solve complex technological problems including; breaking problems down into their component parts, focusing the attention of problem-solvers on relevant tasks, encouraging and interweaving planning and action, and using cognitive artefacts such as paper, pencils, diagrams and prototypes or models. Although no assumptions were made in this thesis as to which interpretation or model the participants would adopt, it is argued that during Study 1 the participants problem-solving strategies support the interpretations by Bransford and Stein, Deluca, Payne and Green.
To reduce the use of tacit knowledge and automated procedures the design challenge of Study 1 was designed to be complex and difficult to solve. As a result the technological problem in Study 1 was ill-defined, where some aspects of the problem were vaguely stated and was knowledge rich in that a lot of prior knowledge was needed to solve the problem (Robertson, 2001). In addition, the problem type required the problem-solver to be semantically rich so that he/she can bring to bear a lot of experience of the problem type (Robertson). In addition, it also required the problem-solver to be able to interpret and classify the problem or sub-problems in terms of the strategies needed to solve them (Payne, 2001).

The data collected during Study 1 is interpreted as indicating that the three participants were able to break the problem down into its component parts successfully, interpret and analyse the constraints of the design brief and set goals that would enable them to solve the problem. This is interpreted as indicating that the participants exhibited expert-like problem-solver behaviour. This outcome supports the position of Bransford and Stein (1984) who argue that expert problem-solvers usually break complex problems into smaller sub-problems that are easier to solve thereby simplifying the complexity of the problem. In contrast, the deployment of high numbers of Executive Control procedures and low numbers of Generation procedures by all of the participants is interpreted as indicating that they lacked depth of knowledge and experience of the problem type. As a result the participants devoted a large number of cognitive procedures toward deciding what to do and when to do it rather than generating new solutions to the problems that they were faced with.

It was also found that the majority of the Generation procedures deployed by the problem-solvers during Study 1 were related to solving design and manufacturing problems in their proposed solutions. Many of these problems were only realised by the participants when they began to manufacture their solutions to the design challenge. This is interpreted as indicating that due to their lack of knowledge with the problem type and the problem domain that the participants were unable to foresee the possible flaws that might arise and the consequences of these flaws in their designs and the problems that developed as a result.
Antonietti (2001) argues that expert-like problem-solvers transfer problem-solving skills, experience and knowledge learnt from previous problem-solving events to new problem domains and problem types. However, for this cognitive procedure to occur, Antonietti notes that the problem-solver must be able to recognise the similarities between the source problem and the new target problem. If this process is successful Bransford and Stein (1984) suggest that the problem-solver can be considered as exhibiting expert problem-solving behaviour. However, on numerous occasions the participants of Study 1 were unable to make this connection, transfer knowledge and experience and draw analogies between previous problem-solving events and the new problems that they faced within Study 1. This is interpreted as indicating the participants are novice-like in their problem-solving behaviour and as a consequence relied upon trial-and-error to solve new problems or sub-problems.

It is interpreted that the participants had no automated solutions to the problems and as a result all participants can be seen to be experimenting with aspects of the problem and the solutions that they generated. This process of experimental trial-and-error resulted in large numbers of Executive Control procedures being deployed and fewer Generation procedures that were associated with creating or developing solutions to the problems. However, the trial-and-error tactics were applied indiscriminately and not in any planned or particular manner. In this case, Robertson (2001) argues that the lack of automated solutions, knowledge and experience in a domain indicates that the problem-solver is semantically lean and therefore considered a novice problem-solver.

Further analysis of the data collected during Study 1 is interpreted as indicating that the participants utilised the physical environment extensively to solve the problems of the design challenge. It can be seen that much of the cognitive processes of the participants was recorded on the paper provided which resulted in the development of a number of solutions in the form of prototypes. Zhang and Norman (1994) argue that this strategy enables the problem-solver to transfer aspects of the cognitive problem-solving process into the physical environment thereby making problem-solving easier. Zhang and Norman state that this transference reduces the cognitive load of problem-solving. Payne (2001) suggests that this is achieved by redrawing the boundaries of the problem to include the artefacts that are available, such as pencil and paper.
Green (1989) argues that the process of recording events of the problem-solving process on external artefacts such as paper indicates that the problem-solvers are developing an information system that makes retrieval of relevant data easier. In addition, Green claims that recording data externally makes performing certain problem-solving activities simpler. Payne (2001) contends that this strategy changes the internal memory trace of the data thereby allowing the problem-solver to access the information with less effort which in turn allows the problem-solver to access and retrieve information more promptly. In addition, Payne suggests that this strategy assists in the problem-solving process; however, it does not guarantee a solution to the problem. It is argued that the participants in Study 1 used this strategy in an effort to reduce the cognitive load, thereby, making the problem easier to solve. However, Goker (1997) surmises that in addition to these strategies, domain knowledge is an important factor when solving problems of a particular nature. As a result, it is argued that the participants viewed the design challenge of Study 1 as a problem rather than a task. Robertson (2001) believes that if the problem-solver does not know how to resolve a difficult challenge, the problem-solver considers the challenge to be a problem rather than a task.

Analysis of the results of Study 1 also revealed that tensions exist between the automated expert-like knowledge and strategies of the participants and the lack of solutions and analogies they are able to draw on to solve a new problem type in a new problem domain. As a result it is interpreted that the participants of Study 1 applied a combination of both expert-like automated problem-solving skills when they were confronted with problems or sub-problems that they were familiar with and novice-like problem-solving strategies when they were confronted with problems or sub-problems that were new to them. In addition, it is argued that the participants worked backwards from the goal of creating a packaging that could also be used as a lampshade. This interpretation supports the argument of Larkin et al. (1980) (in Payne, 2001) who states that novices tend to work backwards from the goal or solution whereas experts tend to work forward from the problem statement toward the problem goal or solution. It is argued that this strategy was applied by the participants as it enabled them to apply trial-and-error tactics while searching for knowledge or solutions from similar problems (Larkin et al., 1980 in Payne, 2001).
CHAPTER 6

RESULTS AND PROCEDURE ANALYSIS of STUDY 2

6 INTRODUCTION

Study 2 investigated the manner in which pre-service Technology teachers solve technological problems using a specific strategy or heuristic. Study 2 was based on a Brisbane Library design challenge which was solved using the ASIT problem-solving process. The following sections present and analyse the results for the three participants in terms of their cognitive responses whilst undertaking Study 2.

ASIT is an acronym for the Advanced Systematic of Inventive Thinking (Horowitz, 2001). ASIT is a technological problem-solving process derived from a more complex problem-solving system known as TRIZ. ASIT was chosen as the technological problem-solving process for Study 2 as it was found to be significantly simpler to understand and apply to ill-defined technological problems than TRIZ in the university classroom.

ASIT seeks to solve ill-defined technological problems by directing the problem-solver through a number of simple steps and applying a series of rules. These rules include: defining the Problem World, identify the aggravating factors and if any aggravating factors or elements are found, turn them into beneficial or neutral ones, and finally, searching for a solution that does not add any new type of objects to the Problem World (Horowitz, 2001a). ASIT is discussed in detail in 3.11.

It was predicted that the participants would explore where, when and in what circumstances they should apply the ASIT rules. It was also envisaged that the ASIT problem-solving strategy would guide the participants’ problem-solving attempts and enable them to generate and develop plausible solutions to the Brisbane Library design challenge. The following sections discuss the interpretation of results for three participants in terms of their cognitive responses whilst undertaking Study 2. Three cognitive procedures were monitored during the tasks: Exploratory, Executive Control and Generative procedures as was done in Study 1. Exploration procedures are
defined as involving the exploration of a problem context and constraints as well as
the various attributes and elements of those constraints. Exploration procedures also
include the investigation of possible solutions or solution elements. Executive Control
procedures are concerned with the process of planning, monitoring and evaluating
what to do and when to do it. Generation procedures are those involved with the
generation or creation of a solution or solutions to a problem.

6.1 Study 2 - The Brisbane Library
The following sections present and analyses the results of the three participants whilst
apply the ASIT problem-solving process to the Brisbane Library case study.

6.2 Participant B
Participant B was a 22-year-old male, third year student, and was a high school
graduate when first enrolled in the BTechEd program as a student teacher. Participant
B had no previous trade or technical training experience or qualifications. Participants
were allowed 60 minutes to complete Study 2; however, Participant B completed
Study 1 in 37 minutes and 30 seconds.

Participant B’s procedures whilst completing Study 2 are illustrated graphically in
Figure 15 as a scatter-plot. The scatter-plot divides the transcript into ten equal units
by time, or tentiles, and the number and type of procedures deployed during each
Tentile are represented.
6.2.1 Exploration Procedures

Exploration procedures involve the exploration of a problem context and constraints as well as the various attributes and elements of those constraints. During Study 2 Participant B’s deployment of Exploration procedures began immediately in Tentile 1 peaking at Tentile 3 where 14 instances of Exploration procedures were deployed. Tentile 3 was the first of two peaks, the second peak can be seen in Tentile 10, the last Tentile, where Participant B deployed 16 Exploration procedures.

This section of the transcript is dominated by the deployment by Exploration procedures, in particular, Exploring Attributes [EA]. The manner in which Participant B explores these attributes is constrained by the ASIT problem-solving strategy which requires the problem-solver to list all objects in the ASIT Problem World. In T3 07:37 below Participant B can be seen developing the elements contained within the ASIT Problem World:
T3 07:37

22. so … old library [EA]
23. so … new library [EA]
24. however the library only has a budget of $50,000 to the books and the estimates from the moving company exceed the budget [EA]
25. okay [MO]
26. so then we've got old to new [EA]
27. books that we are moving [EA]

However, after the initial exploration of attributes, Participant B switched to exploring the constraints of the problem and the problem context using the ASIT problem-solving process. The T4 11:18 below shows Participant B investigating the parameters of the ASIT Closed World:

T4 11:18

10. so there are a couple of types here [SF]
11. the Closed World [EC]
12. means no new types of objects can be bought in [EC]
13. so in the Closed World I can use what's here and … [EA]
14. so I will just jot these down first [MO]
15. no new types … can be introduced … [EC]
16. and Qualitative Change means that … [EC]
17. Qualitative Change conditions [EC]
18. the relationship between the Undesired Side-effect [EC]

After Tentiles 3 and 4 there is a steady decline in the deployment of Exploration procedures leading to the lowest number of Exploration procedures being deployed during Tentile 7. However, after Tentile 7 Exploration procedures steadily increased again through to their highest level during the task at Tentile 10 at which point there were 16 Exploration procedures deployed. The T7 21:01 below is indicative of the low number of coded procedures including Exploration procedures deployed during Tentile 7:
In T7 21:01 Participant B can be seen exploring the attributes of ASIT whilst trying to understand what the ASIT problem-solving strategy will allow him to do. In this instance Participant B has concluded that he has to work with what is contained in the problem and nothing else (this is one of the fundamental Rules of the ASIT process). However, the uncoded verbalisations and the incomplete sentences are interpreted as indicating the Participant B was experiencing difficulty responding to the design challenge and applying the ASIT problem-solving process.

During Tentile 10, the final stage of the design challenge, when it was expected that Participant B would be exploring the attributes of the solution that he had generated in Tentile 8 Participant B can be seen continuing to deploy Exploration procedures whilst investigating the constraints of the problem using the ASIT problem-solving process. T10 31:24 below illustrates this stage of exploration:

T10 31:24

35. Select an object that would normally be a problem object [EC]
36. Environmental [EA]
37. to do this create a list of variables or characteristics [EC]
38. in different places the books will have different values [EA]

Participant B can be seen above listing the attributes of the problem as he had earlier in Tentile 2 and was continuing to identify and prioritise the information described in the design brief. This reiteration of the constraints of the ASIT Problem World and the ASIT problem-solving strategy suggests that Participant B was exhibiting expert-like
problem-solving behaviour in that he searching along a productive instead of unproductive path (Simon, 2001). However, a review of the video, transcript and written evidence illustrates that Participant B was experiencing significant difficulty understanding the ASIT problem-solving strategy and applying it to resolve the design challenge.

6.2.2 Executive Control Procedures

Participant B deployed a total of 161 Executive Control procedures during Study 2. This large number of Executive Control procedures is interpreted as indicating that Participant B was engaged in a complex task that he found difficult and that he was unable to execute any automated problem-solving procedures. Executive Control procedures are concerned with the process of planning, monitoring and evaluating what to do and when to do it and this process is demonstrated during Study 2 in two distinct peaks.

The first of two peaks in the deployment of Executive Control procedures can be seen in the scatter-plot (Figure 15) at Tentile 4. During Tentile 4 of the 41 Segments coded Participant B deployed 27 Executive Control verbalisations that included eight Strategy Formulations [SF] and eight Goal Switching [SW] procedures. Strategy Formulation [SF] in this context relates to an indication of a general heuristic for approaching a problem or parts of a problem (Schön, 1990) while Goal Switching [SW] procedures are an indication of a change of attention from one aspect of the problem to another (Eckersley, 1988). T4 11:18 below illustrates the context in which several of the Strategy Formulations [SF] and Goal Switching [SW] verbalisations were made:

T4 11:18

1. ummm … [SW]
2. so … this will be a sheet that I will refer to throughout solving the problems [SF]
3. it's just got the basic information that I would need [MO]
4. so … I told … [SW]
5. so … I can come back and refer to my problem-solving tools [SF]
6. in the middle we've got [SW]
7. that's the visual of the brief with all the major information [MO]
8. ummm … [SW]
9. and I am just continuing to break down the brief into all its sections [SF]

In T4 11:18 Participant B can be seen in the early stages of planning his approach to solving the problem while at the same time switching from one goal or direction to another in a short space of time. In this short excerpt Participant B switches goals and direction four times from discussing the sheet of paper that he has recorded some basic information on to breaking down the design brief further into smaller sections. As can be seen in the scatter-plot the deployment of Executive Control procedures continued throughout the entire study. In addition, dispersed amongst the coded verbalisations during Tentile 4 Participant B deployed a significant number of uncoded delaying or pausing periods. These un-coded verbalisations can be seen below in T4 11:18:

T4 11:18

18. the relationship between the undesired side-effect [EC]
19. okay … [?]
20. so … [?]
21. so … [?]
22. okay … [?]
23. so … [?]

This period of uncoded segments appears after Participant B has read from the ASIT handout and concluded that there is a relationship between the Undesired Effect (Horowitz, 2001) of an element within a problem and its relationship to the ASIT Qualitative Change (Horowitz) condition. These uncoded segments are interpreted as indicating that Participant B was having difficulty proceeding during this period of Tentile 4 rather than indicating deep analysis or understanding of the problem. As a result Participant B switches from this line of exploration to establishing the Problem Statement (Horowitz) as seen below in Segments 24-26 of T4 11:18:
During Tentile 5 there is a noticeable decline in the deployment of Executive control procedures as Participant B continues to explore the context of the problem using the ASIT problem-solving process. This rise in the deployment of Exploration procedures and the decline in Executive Control procedures is interpreted as a response to the ASIT problem-solving process. ASIT is structured in such a manner as to force the problem-solver to explore all aspects of the problem so as to find a solution from within the Problem World (Horowitz, 2001).

6.2.3 Generation Procedures

Generation procedures are those involved with the creation of a solution or solutions to a problem. During the ASIT design challenge Participant B deployed a low level of Generation procedures until later in the design challenge. This low deployment pattern was maintained until Tentile 7 where Generation procedures increased from zero to four procedures, the highest number to be recorded during the design challenge. At this point the Generation procedures plateaued and remained at four through to Tentile 9 where they again declined to zero.

During Tentile 4 Participant B spent a considerable amount of time working through the ASIT problem-solving process. This exploration later led to the generation of a plausible solution to the problem. However, the transcript and video also revealed that Participant B found the application of the ASIT problem-solving strategy difficult when applied to a problem. This led to a significant revision of his application of the ASIT problem-solving strategy during the design challenge. In T5 14:19 below Participant B can be seen deploying a number of Generation procedures during the design challenge:
I'm trying to class the Problem Objects and the Environmental Objects because sometimes I mixed it up when doing these in the past [SF].

So I think [MO], although I can't remember [RE]. The environmental objects would be the transport, the books [EA].

However, these Generation procedures did not always yield positive outcomes as can be seen in Segment 3. Here Participant B deployed a Retrieval [RE] procedure, which is the retrieval of knowledge from long term memory (Finke, 1989, in Middleton, 1998), in an effort to clarify the difference between Problem Objects and Environmental Objects (Horowitz, 2001). However, he failed to recall the definition of each parameter and as the video illustrates he then returned to reading the definitions from the ASIT handout which resulted in the deployment of the Exploring Attributes [EA] procedure in Segment 4.

Declines in all three categories of procedures were witnessed during Tentile 7 and although there are 21 segments of verbalisations recorded during this tentile seven of the 21 were unable to be coded as they included ambiguous verbalisations, as seen in T7 21:01 below:

Ummm … [?]  
God … [?]  
so I guess … [?]

These uncoded verbalisations are interpreted as indicating the Participant B was finding the problem difficult to solve. Johnson (1964) argues that participants pause during verbalisations when they experience difficulties in solving a problem. Despite the deployment of low levels of Generation Procedures; however, Participant B did generate a plausible solution to the problem in the later half of Tentile 8 and early in Tentile 9. The generation of this solution can be seen to occur during T8 24:42 and T9.
29:23. This occurred at a time when Participant B was applying the Multiplication rule (Horowitz, 2001):

**T8 24:42**

15. So in multiplication you can bring in the same or similar objects [EC]
16. what we could do … is multiply the funds [SY]
17. They…. are one of the underlying problems [MO]
18. so maybe we could try and raise more … raise money [SY]
19. this could be done through … fundraising events [SY]
20. Ummm … [SW]
21. So Community [SF]
22. Community … they could ask for donations [SY]
23. Ahhh … [?]
24. The … the city itself [EA]
25. because it is the … [EA]
26. I guess because it is the Brisbane library which is part of … the
   Brisbane City Council … [EC]
27. I guess so [MO]

**T9 28:23**

1. so they could request more money from the city council or … [SY]
2. Multiplication [SW]

In T8 24:42 above it can be seen in Segment 16 that Participant B proposes to multiply the funds that are available to move the books and continues to investigate how this solution might be achieved. However, immediately following this proposal, Participant B switches his attention to applying the Multiplication rule to other elements of the Problem World (Horowitz).

Over the length of the design challenge, 328 Segments of Participant B’s verbalised thoughts were coded. Of this number 65 Segments or approximately 20% were unable to be coded due to the ambiguous nature of their content. In addition, of the 260 remaining segments that were coded only 11 of these were Generation procedures or approximately 4% of the total coded segments. This is interpreted as indicating that
the vast majority of Participant B’s cognitive attention was devoted to exploring and revising the constraints of ASIT and the problem as well as planning what to do next rather than generating solutions to the problem.

6.2.4 Summary

Study 2 was intended to be a complex and difficult problem to solve; however, Participant B appeared to add to the difficulty of the design challenge by continually revising and re-familiarising himself with the ASIT problem-solving process. This combination of events is interpreted as indicating that Participant B did not have a strong source of automated ASIT problem-solving procedures available to him and therefore remained in the process of re-learning the ASIT methodology and its application while engaging in the design challenge. This lack of usable procedures is interpreted as indicating that in this context Participant B is viewed as semantically lean and exhibiting novice-like problem-solving behaviour when using ASIT (Robertson, 2001).

The trend of low numbers of Generation procedures and the high numbers of Exploration and Executive Control procedures being deployed over the length of the design challenge is interpreted as indicating that although the ASIT problem-solving strategy encouraged Participant B to explore the constraints of the problem and to evaluate what to do next it may have also hindered his ability to deploy Generation procedures and create further plausible solutions to the problem. However, in response to the ASIT design challenge Participant B did persevere and as a result was able to generate a plausible solution to the problem using the ASIT methodology. Participant B’s solution was generated by applying the Multiplication rule (Horowitz, 2001) and as a result, the solution that was generated was to collect more money for the book removal exercise.

6.3 Participant G

6.3.1 Exploration Procedures

Participant G was a 28-year-old male, third year student, enrolled in the BTechEd student teacher program. He was a third year student with a formal trade qualification
as an auto-mechanic. Participants were allowed 60 minutes to complete Study 2; however, Participant G completed Study 1 in 35 minutes and 07 seconds.

Exploration procedures involve the exploration of a problem context and constraints as well as the various attributes and elements of those constraints. In Figure 16 below, Participant G consistently deployed Exploration procedures more frequently than either Executive Control or Generation procedures while engaged with Study 2. Four distinct peaks are evident during the design challenge, the first of which appears during Tentile 1.

**Figure 16 Participant G’s Procedures whilst Completing Study 2**

As can be seen in T1 00:00 below Participant G was actively engaged in re-familiarising himself with both the constraints and context of the problem as well as the ASIT problem-solving process:

**T1 00:00**

1. So these are constraints as seen in the design brief [EC]
2. Closed World condition [EC]
3. Closed World means something along the lines of nothing can be bought in to it [RE]
4. so … no qualitative … [EA]
5. sigh … [?]
6. so … Closed world … [EC]
7. no new types of objects can be added [EA]
8. means Qualitative World examines changing the relationship between the undesired effect … [EC]

However, during the second of the peaks in Tentile 3, Participant G can be seen exploring the attributes of the ASIT Closed World in more detail, as seen in T3 08:06 below:

**T3 08:06**

12. borrowers borrow books … [EA]
13. they need to return the books … [EA]
14. the borrowers borrowed from old library returned to new library [EA]

This activity is interpreted as indicating that Participant G was in the early stages of identifying and developing an understanding of all of the known constraints of the problem. The ASIT problem-solving strategy was then applied to these constraints to establish a foundation for solving the problem. This is interpreted as indicating that Participant G is displaying expert-like behaviour. Simon (2001) argues that this indicates that the problem-solver is searching along a productive rather than unproductive path.

The third of the three peaks can be seen at Tentile 6 and appears to confirm the expert-like behaviour seen earlier. In Tentile 6 Participant G, having established what the constraints of the problem are, is now extensively exploring these constraints and applying the rules of ASIT to them (see T6 20:35below). In this instance the Unification rule (Horowitz, 2001) is being explored to see if a plausible solution can be generated from combining the various constraints from within the problem, for example, the books and the budget.

**T6 20:35**

1. the books will prevent the cost increasing budget [EA]
2. the budget will prevent the cost increasing budget [EA]
3. the movers will prevent the cost increasing the budget [EA]
4. the library will prevent the cost increasing the budget [EA]
5. the distance to the library will prevent the cost increasing the budget [EA]
6. the borrowers will prevent the cost increasing the budget [EA]
7. the library staff will prevent the cost increasing the budget [EA]
8. other people will prevent the cost increasing the budget [EA]
9. the Street will prevent the cost increasing the budget [EA]
10. the vehicles on the street will prevent the cost increasing the budget [EA]

At this point it can be seen that Participant G is no longer re-familiarising himself with the ASIT methodology as he was earlier in Tentile 1 of the transcript but rather he is now in the process of applying the ASIT problem-solving strategy directly to each of the elements to find a plausible solution. This is interpreted as indicating that through Participant G’s earlier investigations he has developed a level of knowledge of the ASIT problem-solving strategy that enables him to move on to applying the methodology to solve the problem.

The fourth and final peak of Exploration procedures occurs during Tentile 9 where Participant G is continuing to explore the constraints of the ASIT problem-solving process, in this instance the Multiplication rule (Horowitz, 2001) as seen below in T9 31:24:

**T9 31:24**

26. just getting these ideas out using the multiplication tool [SW]
27. budget be better utilised on attracting more borrowers [EA]
28. borrowers are multiplication [EA]
29. to facilitate moving books by the return system … [EA]
30. by the modified returns system seen earlier … [EA]

Participant G’s exploration using the Multiplication rule (Horowitz, 2001) does not yield a plausible solution; however, shortly after in Tentile 10, the final Tentile, while
deploying only six Exploration procedures Participant G is on the brink of solving the problem while exploring the constraints and attributes of the Division rule, as seen in T10 35:07 below:

**T10 35:07**

19. Division … division, division, division [MO]
20. I think … I think this really relates to … ummm … to dividing [EA]
21. the dividing the number of books across the number of borrowers [SY]

Participant G’s deployment of high numbers of Exploration procedures is interpreted as indicating that he was exhibiting expert-like behaviour whilst following the application of the ASIT problem-solving process. However, as can be seen in T10 35:07 above the ASIT problem-solving strategy, by it very nature, encourages the problem-solver to apply trial-and-error like strategies to work through each of the elements within the Problem World (Horowitz, 2001) rather than use known strategies to solve the problem.

### 6.3.2 Executive Control Procedures

Executive Control procedures are concerned with the process of planning, monitoring and evaluating what to do and when to do it and four peaks of Executive Control procedures can be seen during Study 2. These peaks are relatively evenly distributed throughout the design challenge and appear at Tentiles 2, 4, 6 and 9. During the first of these peaks at Tentile 2 Participant G deployed eight Executive Control procedures, as seen below in T2 04:23:

**T2 04:23**

15. so … unification to bring it together [SW]
16. so now we are just examining the different techniques that we can use under the ASIT problem-solving technique [SF]
17. so … [?]
18. is to … [?]
19. Give me a definition of Unification … definition … [SF]
20. okay [?]
21. that's unification process … [SW]
22. I see that what we are coming up with pretty often prevents or … [SF]
23. as we move over to multiplication [SW]

T2 04:23 above illustrates that Participant G was engaged in the process of planning, monitoring and evaluating what to do and when to do it, or in other words, deploying Executive Control procedures. These Segments of Executive Control procedures followed a period of deploying a large number of Exploration procedures whilst exploring the constraints and attributes of the problem and ASIT. In addition, dispersed amongst these procedures are a number of uncoded verbalisations and pauses. This combination of Goal Switching [SW], Strategy Formulation [SF] and uncoded verbalisations is interpreted as indicating that Participant G was finding the problem difficult to solve and that he had not yet re-familiarised himself with the ASIT problem-solving strategy or the constraints of the problem.

The second peak at Tentile 4 is similar in outcome to that of Tentile 2. However, his verbalisations on this occasion are interpreted as indicating that his understanding of the ASIT problem-solving strategy and the constraints of the problem has advanced, as can be seen below in T4 12:29:

**T4 12:29**

15. now that we have done … [SW]
16. now that I have made some early ideation let's go through the and have a look at our physical … [SF]
17. at the actual ASIT tools to ummm … further build on or maybe ideate some new ASIT ideation [SF]
18. how could we … [SW]

The above Executive Control procedures are interpreted as indicating that Participant G is in the process of planning his problem-solving approach and the application of the ASIT problem-solving process.

Although 11 Executive Control procedures are deployed during Tentile 6 they are more evenly dispersed throughout the coded segments rather than clustered together.
as in Tentile 4. This is interpreted as indicating that during Tentile 6 Participant G was more deeply engaged in the process of planning, monitoring and evaluating what could be done with the information and ideas that he had already formulated in the previous tentiles. For example, in the following excerpt (T6 20:35) Participant G can be seen to be evaluating [EV] the merits of a solution he had just proposed:

**T6 20:35**

29. I think there is really something in the book borrowers moving the books to the new location [SY]
30. it is simple it doesn't add anything in … [EV]
31. it's a process that is going to occur anyway … ummm … whether they had to come back to the original location or they had to go further … [EV]
32. ummm … [?
33. or a new location [EA]

An initial interpretation of this procedural deployment is that Participant G was displaying expert-like problem-solving skills (Simon, 2001) when applying the ASIT problem-solving process. Closer examination reveals; however, that Participant G was unable to recognise that he had solved the problem, indicating novice-like rather than expert-like problem-solving behaviour (Simon, 2001). This result supports the argument of Robertson (2001) that in this instance, Participant G lacks a depth of knowledge of the problem area and is therefore Semantically Lean and has little experience of the problem type.

The fourth and final peak of Executive Control procedures occurs at Tentile 9 and like Tentile 6, the deployment of Exploration procedures are dispersed throughout the coded segments rather than clustered as in Tentile 4. However, during Tentile 9 Participant G deployed a greater number of Executive Control procedures than in any other Tentile. Early in the tentile Participant G deployed a number of Goal Switching [SW] and pauses [?] procedures that are interpreted a indicating that at this point he was finding the problem and the application of ASIT difficult, this is highlighted in T9 31:24 below:
In addition, in some instances it was unclear as to the connection between the verbalisations and the problem at hand as can be seen below in the following Segments of T9 31:24:

**T9 31:24**

1. … (long pause) [SW]
2. Let's have a look here multiplication [SW]
3. ummm … [?] 
4. just go back to examining some … for ideas [SW]
5. ummm … [?] 
6. ummm … [?]

The relationship of the fish to the current problem was not initially clear therefore further analysis of the video evidence was required. The video evidence revealed that Participant G was attempting to relate a solution from an ASIT exercise performed in the Design Processes class in the first year of his degree to the current ASIT design challenge. However, the transcript shows Participant G did not continue with this line of thought and later Switched (SW) to the ASIT Multiplication Rule (Horowitz, 2001).

As Participant G progressed through the problem-solving process in Tentile 9 the connection between the verbalisations and the problem-solving process became clearer as can be seen below:

**T9 31:24**

34. Therefore multiplication … [SW]
35. therefore the returns … [SW]
36. the number of returns will be increased [EA]
37. ummm … [?]
38. will be all to move more books … [EA]
39. ummm … [?]
40. to the new location at … [SW]

This series of segments are interpreted as indicating that Participant G was actively engaged in the planning, monitoring and evaluating of the Exploration procedures that were dispersed amongst the Executive Control procedures during this late stage in the Tentile. After Tentile 9 a sharp decline in the deployment of Executive Control procedures was evident.

During Tentile 10 only 27 Segments were coded. Of the 27 segments, seven of these were coded as Executive Control procedures, a number of these as can be seen below in T10 35:07:

**T10 35:07**

18. ummm … [SW]
19. Division … division, division, division [MO]
20. I think … I think this really relates to … ummm … to dividing [EA]
21. the dividing the number of books across the number of borrowers [SY]
22. I really think there is something in that [EV]

Segment 21 above illustrates the period when Participant G revealed a plausible solution to the problem ... *dividing the number of books across the number of borrowers*. The Executive Control procedures deployed during this period are interpreted as indicating that Participant G is in the process of planning, monitoring and evaluating how to develop this solution further.

**6.3.3 Generation Procedures**

Generation procedures are those involved with the creation of a solution or solutions. However, Participant G’s deployment of Generation procedures remained consistently low throughout the design challenge with the exception of Tentile 9 where no Generation procedures were deployed.
Participant G did generate a plausible solution to the problem in Tentile 6 whilst exploring the attributes and elements of the constraints within the Problem World. This generation occurred during Segment 29 when he revealed *I think there is really something in the book borrowers moving the books to the new location.* This Segment was coded as Synthesis or [SY] as it is interpreted as indicating that he is formulating and articulating a specific solution to the problem (Finke, et al., 1989). He then went on to reflect on this solution. It appears from the transcript; however, that he does not recognise immediately that he has generated a plausible solution and instead he progressively moves his attention away from his solution. Robertson (2001) argues this is an indication of a problem-solver who has little experience of the problem type. Participant G then continues deploying Exploration procedures investigating other elements and constraints of ASIT and the problem. Later during Tentile 10 Participant G deployed the greatest number of Generation procedures and the segments below in T10 35:07 indicate that it was the most productive period of the design challenge:

**T10 35:07**

20. I think … I think this really relates to … ummm … to dividing [EA]
21. the dividing the number of books across the number of borrowers [SY]
22. I really think there is something in that [EV]
23. I think ummm … by … by spreading X number of books across Y [SY]
24. whereas simply asking them to Y +1 or you know sorry, X +1 [SY]
25. asking them to borrow a book or borrowing a book … a book plus another or other two that they would not necessarily read and just asking them to facilitate the drop-off at the new location. [SY]
26. I really think there is something in that … [EV]
27. borrowing a book plus another or two … ummm … to drop off at the new location. [SY]

As can be seen above during this period five Generation procedures were deployed and all five were coded as Synthesis [SY]. These Generation procedures resulted in a plausible solution to the problem being realised. However, the final solution came in the last minutes of the study and as a result Participant G was unable to refine and develop the solution further due to the lack of time. However, despite generating a
plausible solution during Tentile 10, Participant G made no verbal connection to the solution he had generated earlier in Tentile 6. This is interpreted as indicating that although Participant G appeared confident with the application of the ASIT problem-solving strategy he was a novice ASIT user which resulted in the inability to recognise a plausible solution when it was first generated.

6.3.4 Summary

The scatter-plot of Participant G for Study 2 illustrates consistently higher deployment of Exploration procedures which coincide with slightly lower numbers of Executive Control procedures being deployed. Overall, Generative procedures are deployed at a low level from the commencement of the design challenge through to the final Tentile. During Tentile 9, Participant G deployed a greater number of Exploration and Executive Control procedures than at any other time during the design challenge. In contrast, during this period Participant G did not deploy any Generative procedures. This is interpreted as indicating that the deployment of Executive Control and Exploration procedures may hinder the deployment of Generation procedures thereby limiting the creation of a solution to the problem during this period. This is evident in Tentile 10 where the deployment of both Exploration and Executive Control procedures was greatly reduced; however, six Generation procedures were deployed resulting in a plausible solution to the ASIT design challenge being generated.

Although Participant G did solve the ASIT design challenge, its resolution was not without significant cognitive load. A total of 323 Segments of verbalisations were coded during Study 2. Of this total 85 were unable to be coded due to the ambiguous nature of their intent and meaning. This represents approximately 26% of all segments in the transcript that were unable to be coded. This high number of un-coded segments is interpreted as indicating that Participant G found the ASIT problem-solving strategy and its application difficult and challenging.
6.4 Participant P

6.4.1 Exploration Procedures

Participant P was a 34-year-old male, third year student, enrolled in the BTechEd student teacher program. He was a third year student with a formal trade qualification as cabinet maker. Participants were allowed 60 minutes to complete Study 2; however, Participant P completed Study 1 in 35 minutes and 37 seconds.

Exploration procedures involve the investigation of a problem context and constraints as well as the various attributes and elements of those constraints. In Figure 17 below, three distinct peaks of Exploration procedures are evident in Participant P’s scatter-plot. These peaks occur during Tentiles 2, 6 and 9 and begin at the opening of the design challenge in Tentile 1.

Figure 17 Participant P’s Procedures whilst Completing Study 2

During Tentile 1 Participant P can be seen to initiate an increasing level of Exploration procedures that peaked during Tentile 2. After Tentile 2 the numbers of Exploration procedures quickly declined, a trend which continued through to Tentile 4. During this period Participant P was investigating the context of the problem and
the various rules of the ASIT problem-solving strategy and the various attributes contained within the problem, as seen below in T1 00:00:

**T1 00:00**

15. we only … we have is a budget of $50,000 to remove the books and all the estimates from the removers far exceed the budget [EC]
16. list all of the conditions [SW]
17. include all the conditions of the Closed World [EC]
18. phew [?]
19. Closed World conditions require that no new types of objects be included into solving of the solution [EC]
20. the Qualitative Change condition examines changing the relationship between the Undesired Effect and the Worsening Factors [EC]

In Segment 15 above Participant P can be seen to be establishing one of the constraints of the problem, in this case the $50,000 budget to remove the books. In Segments 16 Participant P switches [SW] from the various problem attributes and begins to analyse the rules of the ASIT problem-solving process. This exploration continues in Segments 17 and 19 where Participant P is exploring the conditions of the Closed World (Horowitz, 2001a) and again in Segment 20 where he explores the conditions of Qualitative Change (Horowitz, 2001a). This activity is interpreted as indicating expert-like behaviour; however, in the midst of this investigation at Segment 18 Participant P is seen to be expressing an uncoded verbalisation, *phew* [?]. This uncoded verbalisation in the transcript was compared to the activity recorded at the same time in the video where he is seen to be tapping his pen on the desk and scribbling on a piece of paper. This is interpreted as indicating that during this period Participant P was finding the design challenge complex and difficult to solve. Robertson (2001) argues that this is an indication that the problem-solver has little experience of the problem type and lacks a depth of knowledge of a problem area or domain and is therefore Semantically Lean.

Participant P continued with the deployment of Exploration procedures during Tentile 2 which resulted in the highest number of Exploration procedures deployed during the design challenge. However, his attention had switched from the elements and context
of the problem in Tentile 1 to the various elements of the ASIT problem-solving process. This continued during T2 07:05 as can be seen below in the latter half of the Tentile:

**T2 07:05**

41. The books will prevent ummm … the unwanted action [EA]
42. determine the wanted action from the definition [EC]
43. the books will help move [EA]
44. the books will help move the books to the new library [EA]
45. new library … will help move … the books from the old one [EA]
46. The books will move the books to the new library [EA]
47. list all the problem objects [EC]
48. due to the change [SW]
49. problem world [EC]
50. problem world [EC]
51. the problem world is where the books are [EC]

In this excerpt Participant P is applying each of the attributes of the Problem World to the ASIT problem-solving process. The deployment of Exploration procedures early in the design challenge during Tentile 1 is interpreted as indicating that Participant P is identifying and developing an understanding of the context and the known constraints of the problem whilst during the same period re-acquainting himself with the ASIT problem-solving process. The continued deployment of Exploration procedures during Tentile 2 and the switch of attention from the problem to ASIT are interpreted as indicating that Participant P had now established an understanding of the problem and was engaged in the process of solving the problem using the ASIT problem-solving process.

The second peak of Exploration procedures appears during Tentile 6 and although smaller than the peaks at either Tentile 2 or Tentile 9 it is of significance. It is during this period that Participant P reinvestigates the elements of the problem and focuses less on the mechanics of the ASIT problem-solving process, as can be seen below in T6 21:01:
39. staff, helpers, books not Removalist [EA]
40. therefore the Removalist [EA]
41. the Removalists need to transport [EA]
42. ummm … [SW]
43. That’s ummm … at the other end when they unpack it ummm … [EA]
44. the Removalists won’t be unpacking it they will be the volunteers and the staff will be unpacking it [SY]

It is during the deployment of these Exploration procedures that Participant P begins to generate his second solution to the problem. The second solution to the problem can be seen evolving during Segment 44 where he begins to investigate the feasibility of using volunteers to unpack the books. In addition to the higher numbers of Exploration procedures deployed during this period there were also a significant number of uncoded verbalisations made throughout the Tentile. This is interpreted as indicating that Participant P was continuing to find the problem complex and difficult to solve.

The third and final peak of Exploration procedures can be seen during Tentile 9. During this period Participant P continues to investigate the numerous elements of the problem context. However, unlike the previous peak during Tentile 6 where Participant P’s attention was primarily focussed on the elements of the problem. It can be seen below in T9 31:48, that his attention was directed towards both the ASIT problem-solving strategy and its application in this context, in particular, the application of the Division and Multiplication rule (Horowitz, 2001):

T9 31:48
1. Division, Multiplication [EC]
2. Division, division, division [EC]
3. The division tool might be ummm …[EC]

This trend of exploring the ASIT problem-solving strategy continued throughout the Tentile; however, dispersed amongst the coded procedures were also a number of
uncoded segments. This is interpreted as indicating that in this late stage of the design challenge Participant P was continuing to experience difficulty solving the problem.

6.4.2 Executive Control Procedures

Executive Control procedures are concerned with the process of planning, monitoring and evaluating what to do and when to do it. In this case three peaks of Executive Control procedures can be seen in Participant P’s performance during Study 2. These peaks appear to follow the trends of Exploration procedures where three peaks can be seen over the length of the design challenge. The first two of these peaks are quite distinct and appear at Tentiles 2 and 6 while the third lesser peak appears at the end of the study during Tentile 10.

During the first of these peaks at Tentile 2, Participant P deployed 17 Executive Control procedures including; two Goal Setting [GS], one Strategy Formulation [SF] and three Evaluation [EV] procedures. However, the majority of the Executive Control procedures deployed during Tentile 2 were Goal Switching [SW]. Goal Switching [SW] indicates ‘a change of attention from one aspect of the problem to another’ (Eckersley, 1988). During Tentile 2 Goal Switching [SW] accounted for 11 or 64% of the total Executive Control procedures deployed. An example of these Goal Switching [SW] procedures that Participant P deployed during Tentile 2 can be seen below in T2 07:05:

**T2 07:05**

37. I'm using this one here [SF]
38. Ummm … [SW]
39. Multiplication [EC]
40. Ummm what was that ...? [SW]
41. The books will prevent ummm … the unwanted action [EA]

The second of the Executive Control peaks appears at Tentile 6 and again like Tentile 2 the majority of these procedures were Goal Switching [SW]; however, in this case the overall percentage of Goal Switching [GS] procedures was greater than that of Tentile 2. A total of 19 Executive Control procedures were deployed during the period
of which 16 were Goal Switching [SW]. This represents approximately 84% of the total number of Executive Control procedures deployed during the Tentile an example of which can be seen below in T6 21:01:

**T6 21:01**

13. This is from what I can remember ummm … from the class is that you keep spiralling outwards and the further you get away from the solution [RE]
14. Ummm … [?]
15. You’re … [SW]
16. The problem becomes more complex [EC]
17. Ummm … [SW]
18. And … so try to keep it within the box is the … the thing [SF]
19. I think our constraints are … here … [EC]
20. Ummm … [SW]
21. What I'm thinking [EA]
22. Ummm … [?]
23. Is maybe possibly even [SW]
24. I don't know where it is going to fall into what category [MO]
25. ummm … [SW]
26. But instead of having [EA]
27. Ummm … [SW]
28. The price to do that … a price on … a price on … say using volunteers [EA]

Dispersed amongst this lengthy excerpt of 16 segments, six Goal Switching [GS] procedures appear. This indecisive switching pattern is interpreted as indicating that Participant P was experiencing difficulty determining the correct direction and or action to deploy at this stage of the problem-solving process. This trend was not unique to Tentiles 2 and 6 and continued in the third and final peak of Executive Control procedures in Tentile 10. During Tentile 10, 12 Executive Control procedures were deployed of which eight or approximately 67% were Goal Switching [SW].
Overall the high percentage of Goal Switching [SW] procedures deployed during Tentile 6 are interpreted as indicating that Participant P was finding the problem complex and difficult to solve and as a result engaged trial-and-error strategies as he was working through each of the ASIT rules. This is interpreted as indicating that Participant P and was unable to draw on any known ASIT problem-solving strategies to solve Study 2.

6.4.3 Generation Procedures

Generation procedures are those involved with the creation of a solution or solutions to a problem and during Study 2 three peaks of Generative procedures are apparent in the scatter-plot of Participant P. These peaks occurred at Tentile 4, 6 and 9. After Tentile 1; however, where Participant P was engaged in a period of deploying mainly Exploration procedures, he deployed only one Generative Procedure, that of Synthesis [SY], during Tentile 2. This Generative Procedure occurred during the first segment of Tentile 2 and can be seen below in T2 07:05:

T2 07:05
1. (Research Assistant asks ‘what are you thinking?) I am thinking if possibly to help move the books we could use people who are taking the books out from the library when they are hiring the books on loan that the books go back to …ummm ... the new library [SY]
2. Possibly [SW]
3. ummm ... [?]
4. also thinking possibly [SW]
5. ummm ... [?]
6. … (long pause) [?]
7. So [?]
8. ummm ... [?]
9. … (long pause) [?]
10. Ummm … [?]

During Segment 1, Participant P verbalises the first of three plausible ASIT solutions to the problem, in this case he applies the Multiplication rule (Horowitz, 2001) to
arrive at a solution. The proposed solution to use the library borrowers to return their books to the new library thereby will assist with moving the books to the new library.

However, immediately following the verbalisation of this ASIT solution, Participant P deployed a Goal Switching [SW] procedure. The Goal Switching [SW] procedure diverted Participant P’s attention away from his proposed ASIT solution. This event eventually directed him towards investigating alternative solutions using the ASIT problem-solving process.

The immediate deployment of a Goal Switching [SW] procedure after the generation of an ASIT solution to the problem is interpreted as indicating that Participant P was unsure of the validity of his proposed ASIT solution. Further, the number of uncoded verbalisations immediately following his proposed solution are interpreted as indicating that Participant P was not only having difficulty applying the ASIT problem-solving strategy he was also finding the problem complex and difficult to solve and as a result resorted to trial-and-error strategies in attempt to solve the design challenge.

During Tentile 4 Participant P deployed only four Generation procedures, such as: Segment 13 use borrowers to return books ummm … to the new site [SY] or Segment 23 Free helpers to shift books [SY]. However, all four of these procedures were associated with the refinement of the solution that Participant P had suggested in Tentile 2. During Tentile 5 Participant P can again be seen experimenting and using trial-and-error strategies to explore the application of a number of ASIT rules. During Segment 26 of Tentile 5 he can be seen to make the switch from the Multiplication rule to the Division rule. As can be seen below in T6 21:01, this switch lead to the generation and development of a second plausible ASIT solution later in Tentile 6:

T6 21:01

44. the Removalists won't be unpacking it they will be the volunteers and the staff will be unpacking it [SY]
45. Ummm [SW]
46. So they … ummm … will be putting it into all the categories [SY]
47. I don't know … where it's got to go on the racks [SY]
From his initial idea of using the volunteers and staff to move and unpack the books Participant P continued to experiment during the design challenge with a number of ASIT rules. This trial-and-error process culminated in the generation and development of his final plausible ASIT solution in the third and final peak of the design challenge, Tentile 9.

During Tentile 9 Participant P began to combine both the Multiplication rule and the Division rule (Horowitz, 2001). This combination of ASIT rules lead to the generation of a third and final plausible ASIT solution. However, this ASIT solution was not developed quickly and took place over the length of the Tentile. As can be seen below in T9 31:48, Participant P switched and explored between many aspects of the evolving solution, for example:

**T9 31:48**

1. Division, Multiplication [EC]
2. Division, division, division [EC]
3. The division tool might be ummm …[EC]
4. Ummm … [SW]
5. No Changed relationship [EC]

Again later in the T9 31:48, Participant P can be seen deploying trial-and-error strategies to explore the attributes of the elements of the problem and apply the ASIT problem-solving process, as can be seen below:

**T9 31:48**

23. *(Research Assistant asks ‘what are you thinking now?’)* Ahhh … just how to write what I am trying to think [SF]
24. Ummm … [SW]
25. Basically I think it can be linked back to this one [RE]
26. this one is the division of the shift [EC]
27. if instead of shifting the whole library [EA]
28. ummm … [SW]
29. By the volunteers [EA]
30. by the removals company [EA]
31. ummm … [SW]  
32. Divide your most ummm … most popular books that get used and shift them over to the new town library [SY]  
33. ummm … [SW]  
34. But once again does that fit into the realms of fixing the problem [MO]  

This trial-and-error strategy was a long and drawn out process and took place over the length of the Tentile 9. However, the trial-and-error approach eventually led to the generation and development of Participant P’s final plausible solution. This final solution involved combining the ASIT Division rule and the Multiplication rule (Horowitz, 2001) so that between the library borrowers and the removalists a plausible ASIT solution could be found.

6.4.4 Summary  
During Study 2, Participant P generated and developed to varying degrees three plausible ASIT solutions to the Brisbane Library book problem. His first solution was to ask the borrowers to borrow more than one book from the old library and return them to the new library (Multiplication Rule). His second solution was to ask staff and volunteers to pack, move and unpack the books (Division Rule). His third and final solution, also his preferred solution, was to divide the books between the library book borrowers and the removalists to remove the books from the old library and deliver the books to the new library (Division and Multiplication rules combined).

However, it was his final approach to the design challenge, that of combining the ASIT Division and Multiplication rules (Horowitz, 2001), that led Participant P to generate his preferred solution to the design challenge. This combination of ASIT rules led to dividing the library books between the library borrowers and the removalists. In addition, the solution asks the borrowers to borrow several books at one time. This strategy would reduce the number of books the removalists would be asked to move to the new library. With the number of books now divided the removalists would therefore remove the remaining books from the old library and deliver them to the new library thereby saving money and enabling all of the books to be delivered to the new library within budget. Library staff and volunteers would then
be asked to place the books, once delivered to the new library, on the shelves in their designated categories.

Although this is Participant P’s final plausible solution, he does state that he has made several assumptions based on the budget of $50,000 and the limited amount of information available in the design brief. Firstly, that there is no timeframe for the relocation of the books to the new library and secondly that the removalists could remove and deliver the remaining books within budget. In conclusion, Participant P’s indecision regarding the application of the ASIT rules and his trial-and-error strategies lead to a positive yet time consuming outcome and the generation of not one but three plausible ASIT solutions to the design challenge.

6.5 Procedure Analysis across Participants - Study 2

In this section an analysis of the procedures deployed across the three participants (B, G and P) is provided. At the commencement of Study 2, Participant B expressed how interested and excited he was to have been chosen to participate in the study. When he was asked why, he stated that he enjoyed using the ASIT problem-solving strategy and that he had applied ASIT in other areas of his personal and professional life. It was expected therefore that Participant B would not have any difficulty in applying the ASIT problem-solving strategy and would quickly generate a creative solution to the design challenge. However, it was apparent early in the study that Participant B was experiencing difficulty understanding the rules of the ASIT problem-solving strategy and when to apply them. This result conflicted with his earlier statement that he had applied ASIT in other areas of his personal and professional life. As a result of this lack of understanding and sometimes confusion regarding the ASIT problem-solving strategy Participant B spent a considerable amount of time and cognitive effort re-learning and revising the ASIT rules and questioning his decisions. Analysis of Participant B’s transcript indicates that he deployed more Executive Control procedures than either Participants G or P yet he deployed the least number of Generation procedures of the three participants.

The majority of the Executive Control procedures deployed by Participant B were a result of the extensive use of trial-and-error strategies and were not concerned with
how to implement the ideas and solutions that had been generated as a result of his exploration or generation. However, Participant B did generate a plausible solution to the problem, that of multiplying the funds available (Multiplication rule) for the move by means of fundraising, seeking donations from the community and applying to Brisbane Council for more money. Despite this solution, by the conclusion of Study 2, Participant B was still in the process of exploring further the constraints of the problem and the ASIT problem-solving process. In contrast, Participant G, although enthusiastic about being chosen to participate in the study stated that he had not used the ASIT problem-solving strategy since the training course that he attended two years earlier. Participant G did, however, generate a plausible solution to the problem midway through the design challenge during Tentile 6. However, it appears from the transcript and the video evidence that he did not recognise immediately that he had generated a plausible solution to the problem.

Instead of developing and refining the first plausible solution that he had generated, Participant G switched his attention towards investigating other elements and constraints of ASIT and the problem. The ASIT problem-solving strategy encourages this approach; however, in this case further exploration did not lead to the generation of any additional solutions to the problem. Later in the design challenge during Tentile 10 after extensive exploration of the ASIT rules and the various constraints and attributes of the problem, Participant G returned to his original solution, satisfied that it was a suitable answer. Participant G’s final solution was to ask the library borrowers to borrow multiple books from the old library and when they had finished reading them return the books to the new library (Multiplication Rule). It was thought that this solution would eliminate the removalist from the equation altogether.

Participant P was the third and final participant to participate in Study 2. At the beginning of the videotape, and before the participants had began to solve the ASIT problem, Participant P expressed negative feelings about the study and was heard to say to his research assistant that he thought that he had been chosen to participate in the study because of his lack of understanding of the process. This was not; however, the case. Whilst transcribing the videotape it became evident that Participant P was not confident using the ASIT problem-solving strategy and as a result spent a considerable amount of time during the design challenge reading and re-reading the
ASIT handout aloud. However, on a number of occasions during the transcription process Participant P’s verbalisations whilst reading were barely audible. As a result the researcher continually cross referenced the audio recording with the video recording and both of these with the sketches and drawings he had created on his sketch-paper. This process of cross-referencing enabled a clearer understanding of what was being said and done.

As a consequence of his comments it was thought that his results may reflect his negative attitude; however, unlike both of the previous participants, Participant P generated three plausible solutions to the problem. The first of these solutions appeared very early in the design challenge during Tentile 2 and was identical in nature to that of Participant G. This solution was to ask the library borrowers to borrow more than one book from the old library and return them to the new library (Multiplication Rule). Towards the middle of the design challenge Participant P generated his second, although his least preferred ASIT solution, that of asking staff and volunteers to pack-up the books at the old library and then move and unpack the books at the new library (Division Rule).

However, it was his third and final solution that appeared to be the most unique. In the third solution Participant P proposed dividing the library books between the library borrowers and the removalists (Division Rule) and increasing the number of books the library members borrowed (Multiplication Rule). The detail of this solution was explained by Participant P as follows: This solution was to be achieved by a combination of two actions; firstly, ask the library members to borrow a larger number of books than they would normally from the most popular categories and secondly, ask the Removalists to move the remaining less popular books. It was thought that by applying this strategy, the most popular books would be returned to the library earlier than the less popular books thereby guaranteeing that the most popular books would be available to the library members quicker than if they had been moved by the removalists. It was also thought that the remaining books could be moved within the $50,000 budget therefore solving the additional monetary issues.

This solution was Participant P’s preferred solution to the problem and it was also unique to Participant P. It did not appear that it was his expert knowledge of the ASIT
problem-solving strategy or its rules that generated this distinctive solution. ASIT encourages the problem-solver to explore more than one solution to a problem; however, as a result of Participant P’s lack of understanding of the ASIT problem-solving strategy he resorted to applying ASIT rules by a trial-and-error method. However, the end result was a positive one and at the conclusion of the design challenge Participant P had generated three plausible solutions to the problem.

6.5.1 Summary

The design challenge for Study 2 was designed to be both complex and difficult to solve. This was achieved by creating design briefs that contained ill-defined problems, where some aspects of the problem were vaguely stated and that were knowledge rich, in that a lot of prior knowledge was needed to solve the problem (Robertson, 2001). The design briefs also required that the problem-solver be semantically rich, able to where he can bring to bear a lot of experience of the problem type (Robertson, 2001). Further, it was necessary for the problem-solver be able to interpret and classify the problem or sub-problems in terms of the strategies needed to solve them (Payne, 2001). However, despite the complexity of the problem and the difficulty of having to quickly re-familiarise themselves with the ASIT problem-solving strategy all of the participants generated one or more solutions to the problem.

The participants responses to the ASIT problem-solving strategy varied during the design challenge; however, it was common to all participants that when they generated a solution to the problem they quickly switched their attention away from the solution before refining or testing it. This reaction was in response to the ASIT problem-solving strategy which encourages the user to try and find a solution to the problem using each of the ASIT Rules.

At the conclusion of Study 2, Participant B had generated a unique yet plausible solution to the problem. This occurred during Tentile 8 and 9; however, he was unable to capitalise on his idea before the conclusion of the design challenge. Participant G also generated a plausible solution to the problem during Tentile 6 and returned to refine his solution in the final Tentile of the design challenge. His solution of
multiplying the number of books the library members could borrow was shared with Participant P.

Participant P; however, was distinctive in several ways. Firstly, by his own declaration he stated that he felt the least confident when using the ASIT problem-solving process. Regardless of this, he overcame his lack of confidence by deploying the greatest number of Exploration procedures. Secondly, the result of this extensive investigation was the generation of three plausible solutions to the problem, one of which he had in common with Participant G. Finally, his third solution, which was also his preferred solution, combined the Division and Multiplication rules (Horowitz, 2001) an outcome that was unique amongst the participants.

The ASIT problem-solving process closely guided the participants attention toward achieving the final goal of the design challenge. This was particularly true for Participant P, who stated that he was not confident using the ASIT problem-solving process yet he generated three solutions to the design challenge, one of which was unique in this study. In addition, it is argued that the ASIT problem-solving process empowered the participants to concentrate on their goal and on the ideas that drove their designing (Kimbell et al., 2004) whilst working towards a resolution of the design challenge.

6.6 Procedure Analysis across Studies 1 and 2

The design of challenges in Studies 1 and 2 were written to be that were both difficult and complex to solve. In addition, they were structured to ensure that the participants would not be able to solve the problems using automated procedures or tacit knowledge. In addition, both design challenges were constrained by their respective design briefs which outlined the problem-solving strategies that were to be used and the constraints that were to be observed. As a result the data collected indicates that all of the participants found the design challenges difficult to solve and relied on trial-and-error as their primary problem-solving strategy. Tables 6, 7 and 8 display the numbers of procedures that the participants deployed in each of the categories, Generation, Exploration and Executive Control. In addition, the tables highlight a number of similarities across participants and design challenges.
Study 1 enabled participants to use whatever problem-solving strategies they had available to them. The design brief stipulated that the packaging solution was also to be used as a lampshade, thereby creating a symbiotic relationship between the components of the design and the final solutions. In addition, the participants’ designs were also constrained by the materials that were available to them for manufacturing their solutions; however, the materials could take on any properties the participants nominated.

In contrast, the design brief of Study 2 stipulated that it was to be solved using only the ASIT problem-solving process. ASIT directs the problem-solver to generate a solution to a problem by using only those elements contained within the Problem World (Horowitz, 2001) in this case, the books, borrowers and Removalist. In addition, ASIT directs the problem-solver to investigate all of the constraints and attributes of both the Closed World and the Problem World (Horowitz). The result of these two studies can be seen in Tables 6, 7 and 8 below:

**Table 6 Participant B’s Procedure Analysis across Studies 1 and 2**

<table>
<thead>
<tr>
<th></th>
<th>Generation</th>
<th>Exploration</th>
<th>Executive Control</th>
<th>Total Coded Procedures</th>
<th>Total Uncoded Procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study 1</td>
<td>31</td>
<td>14.76</td>
<td>87</td>
<td>41.43</td>
<td>210</td>
</tr>
<tr>
<td>Study 2</td>
<td>11</td>
<td>4.18</td>
<td>91</td>
<td>34.60</td>
<td>263</td>
</tr>
</tbody>
</table>

(* % of Total Coded Procedures)
Table 7 Participant G’s Procedure Analysis across Studies 1 and 2

<table>
<thead>
<tr>
<th>Participant G - Procedure Analysis across Studies</th>
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<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Generation</td>
<td>* %</td>
<td>Exploration</td>
<td>* %</td>
<td>Executive Control</td>
<td>* %</td>
</tr>
<tr>
<td>Study 1</td>
<td>35</td>
<td>17.77</td>
<td>57</td>
<td>28.93</td>
<td>105</td>
<td>53.30</td>
</tr>
<tr>
<td>Study 2</td>
<td>32</td>
<td>13.45</td>
<td>129</td>
<td>54.20</td>
<td>77</td>
<td>32.35</td>
</tr>
</tbody>
</table>

(* % of Total Coded Procedures)

Table 8 Participant P’s Procedure Analysis across Studies 1 and 2

<table>
<thead>
<tr>
<th>Participant P - Procedure Analysis across Studies</th>
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<th></th>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Generation</td>
<td>* %</td>
<td>Exploration</td>
<td>* %</td>
<td>Executive Control</td>
<td>* %</td>
</tr>
<tr>
<td>Study 1</td>
<td>67</td>
<td>20.30</td>
<td>143</td>
<td>43.33</td>
<td>120</td>
<td>36.36</td>
</tr>
<tr>
<td>Study 2</td>
<td>25</td>
<td>8.25</td>
<td>155</td>
<td>51.16</td>
<td>123</td>
<td>40.59</td>
</tr>
</tbody>
</table>

(* % of Total Coded Procedures)

In all cases where the participants were not constrained as to what problem-solving strategy they could use, as in Study 1, the participants deployed fewer Generation procedures and greater numbers of Exploration procedures. However, when the participants were constrained by the ASIT problem-solving strategy as in Study 2, the participants deployed greater numbers of Exploration procedures and fewer Generation procedures than in Study 1. Based on the data collected it is argued that the structured rules of ASIT restrict the deployment of Generation procedures. However, ASIT compensates for fewer Generation procedures by forcing the problem-solver to deploy larger numbers of Exploration procedures. This is achieved
by guiding the deployment of trial-and-error tactics to test the plausibility of solutions derived from within the Problem World (Horowitz, 2001).

This is illustrated in Table 6. Here it can be seen that during Study 1 where Participant B was not constrained by the ASIT problem-solving strategy he deployed 87 Exploration procedures and 31 Generation procedures that resulted in a plausible solution to the design brief being created. However, when he was restricted to using the ASIT problem-solving strategy, Participant B deployed 91 Exploration procedures compared to only 11 Generation procedures, yet with fewer Generation procedures being deployed a plausible solution was still created.

Generative procedures are those involved with the generation or creation of a solution or solutions. This category comprises of Retrieval [RE] - retrieval of knowledge from long-term memory (Finke, 1989), Synthesis [SY] - formulation and articulation of a specific proposal to solve a problem or sub-problem (Finke, 1989) and Transformation [TR] - modification of a proposed idea to enable it to solve a particular problem (Weber, Moder and Solie, 1990). During Study 1 Participant B deployed 87 Exploration procedures and 31 Generation procedures; however, it is the make up of the Generation procedures that indicates the differences between the two design challenges.
In Figure 18, Participant B can be seen to deploy two distinct peaks of Generation procedures at Tentile 6 and Tentile 9. The deployment of Generation procedures during these Tentiles was not focused on generating ideas for solving the original problem, as this had occurred between Tentiles 3 and 5. These two peaks of problem-solving process were focused on synthesising [SY] specific ideas and proposals already developed during the design challenge to manufacture firstly the packaging solution in Tentile 6 and secondly the lampshade solution in Tentile 9.

The pattern of deploying low levels of Generation procedures early in the design challenge while designing a solution to the problem and then deploying higher levels of Generation procedures to manufacture the solution was common across all three participants. In addition, the deployment of high levels of Generation procedures corresponded to episodes of trial-and-error procedures where the participants were attempting to solve faults in their designs or in the manufacture of their final products. This result is interpreted as indicating that the participants were not engaged in designing or planning their solution thoroughly in advance nor were they able to foresee problems or errors that may occur in their design until they were involved in the manufacturing process. It is at this point that the participants deployed the greatest numbers of Generation procedures in response to the outcomes of the trial-and-error
designing and manufacturing strategy. However, at the conclusion of Study 1 all of the participants had designed and manufactured a plausible solution to the problem.

Compared with Figure 18 of Study 1, Figure 19 of Study 2 illustrates a very different pattern. There are fewer Generation procedures deployed over the length of Study 2 than in Study 1 and the peaks occur as a result of the participants exploring the constraints and attributes of the problem in attempt to generate a solution. The peaks in Study 1 appear to occur as a result of applying trial-and-error to solve unforeseen design or manufacturing errors.

**Figure 19 Participants Generation Procedures - Study 2**

The data in Table 9 is interpreted as indicating that constraining the problem-solver’s resources to only those present in the ASIT problem-solving strategy results in the deployment of higher numbers of Exploration procedures.
The resulting higher numbers of Exploration procedures may also discourage the deployment of Generation procedures. The Generation procedures that are deployed appear to be directed by the ASIT problem-solving strategy towards creating a plausible solution to the problem rather than in response to applying trial-and-error strategies to solve flawed designs and manufacturing techniques as in Study 1. Where the participants relied on trial-and-error strategies to solve design flaws in Study 1 in Study 2 they relied on trial-and-error strategies as a means of applying the ASIT rules and exploring the constraints and attributes of the ASIT world. This led all the participants to undertake a lengthy process of exploration that also resulted in the deployment of lower numbers of Generation procedures.

Analysis of the data collected in Study 1 reveals that the problem-solving model that was applied by the participants was a combination of Bransford and Stein’s (1984), Deluca’s (1992) and Green’s (1989) explanations. This combination of interpretations produces a problem-solving model that breaks down a problem into its component parts (expert), focuses the attention of the problem-solver on relevant tasks and adopts a trial-and-error (novice) or opportunistic strategy in order to resolve complex technological problems.

The participants, while displaying expert-like problem-solving behaviour when confronted with familiar elements of the problems and sub-problems, applied trial-
and-error strategies at times where they had exhausted the transfer of knowledge and experience from previous problems. It can be seen during the problem-solving events that during these periods of trial-and-error the participants where adding to their repertoire of experience ‘on-the-run’ or during the actual problem-solving event. As the problem event progressed the participants can be seen to make decisions based on the new information gained from their trial-and-error episodes and transferring this new knowledge and experience forward to other areas of the problem or sub-problems.

Horowitz (2001) argues that the problem-solving strategies that are incorporated into the ASIT heuristic overcome the cognitive phenomenon referred to as functional fixedness. Duncker (1945) maintains that functional fixedness prevents the problem-solver from viewing objects in a new light or using them in a new manner. However, Duncker notes that functional fixedness is not limited to physical objects but also mental objects and concepts.

Horowitz (2001a) argues that ASIT is able to overcome this cognitive state by determining the required action that is needed to solve the problem and then trying to use each of the objects in the Problem World to carry out this function. This action is interpreted as Goal Switching [SW]. Eckersley (1988) suggests that Goal Switching [SW] is a change of attention from one aspect of the problem to another. Horowitz claims that this strategy overcomes the problem-solver’s preference to view the functions, abilities and features of an object as fixed. Horowitz surmises that this strategy encourages the problem-solver to view the functions, abilities and features of an object in a new light or to have a function/s that are different from its regular function and can therefore be used in a new context. As a result, Horowitz contends that the problem-solver applying ASIT has a greater chance of generating a plausible solution to the problem from the objects contained within the Problem World than if this strategy were not used.

The degree of functional fixedness in Studies 1 and 2 is indicated by the number of Goal Switching [SW] procedures that were deployed during each problem-solving episode. Analysis of the data indicates that in all cases the participants deployed fewer numbers of Goal Switching [SW] procedures during Study 1 and a greater number of
Goal Switching [SW] procedures during Study 2. Table 10 illustrates this trend in the results.

Table 10 Goal Switching [SW] Procedure across Participants - Study 1 and 2

<table>
<thead>
<tr>
<th>Goal Switching [SW] Procedure across Participants - Study 1 and 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants</td>
</tr>
<tr>
<td>Study 1</td>
</tr>
<tr>
<td>Study 2</td>
</tr>
</tbody>
</table>

These results are interpreted as indicating that the participants displayed a greater tendency towards functional fixedness in Study 1, where they applied trial-and-error strategies, than in Study 2 where they applied the ASIT problem-solving process.

6.7 Conclusion

As described earlier, the design briefs for Study 1 and 2 were created with the intention that they would be ill-defined, complex and difficult to solve. These criteria were achieved by developing design challenges where some aspects of the problem were vaguely stated and required that the problem-solver apply a lot of prior knowledge to solve the problem (Robertson, 2001). In addition, the problem types also required the problem-solver to be semantically rich, bringing to bear a lot of experience of the problem type (Robertson) and able to interpret and classify the problem or sub-problems in terms of the strategies needed to solve them (Payne, 2001).

The data collected during Study 1 reveals that when participants are given the opportunity to choose a problem-solving strategy to solve technological problems they apply known procedures then default to trial-and-error strategies rather than deploying any known structured problem-solving strategies. In addition, the results of both Studies 1 and 2 reveal that the participants combined a number of strategies including: interweaving planning and action, breaking complex problems down into
smaller component parts and using cognitive artefacts such as paper, pencils diagrams and prototypes or models at times that were not required by the design brief but were required by the act of designing. The transcripts, video evidence and artefacts confirm that a combination of these strategies was applied in both Studies 1 and 2. This outcome supports the literature and findings of Payne (2001), Bransford and Stein (1984), DeLuca (1992) and Green (1989). However, as argued by Green (1989) these strategies have a cognitive cost and as a result cause the problem-solver to frequently evaluate, re-evaluate and modify their solutions to a problem.

It is concluded in this thesis that the cognitive cost of problem-solving is illustrated in Study 1 by the low number of Generation procedures deployed and consequently the limited number of new ideas and solutions presented. In addition, a large proportion of the Generation procedures that were deployed during Study 1 were the result of solving unforseen design or manufacturing errors. In contrast, the majority of Generation procedures deployed over the length of Study 2 were the result of the participants exploring the constraints and attributes of the problem and generating solutions to problems.

The data collected during Studies 1 and 2 is interpreted as indicating that all participants exhibited expert-like problem-solving behaviour when breaking the design briefs into smaller manageable sub-problems and relevant information thereby simplifying the complexity of the problem. Additionally, they were able to interpret and analyse the constraints of the problem successfully and as a result were able to set relevant goals that led to a successful solution to the design challenges. This is interpreted as indicating that the participants were able to transfer prior designing knowledge and experiences of the problem domain and the problem type from previous problem-solving events. This result supports the argument of Simon (2001) that an expert’s prior knowledge guides their search along productive paths, thereby eliminating the need for extensive searching.

It is argued by Antonietti (2001) that problem-solvers transfer problem-solving skills, experience and knowledge learnt from previous problem-solving episodes to the new domain and problem type. However, Antonietti states this only occurs if the problem-solver recognises the similarities between the source problem and the new target problem and is thereby able to draw analogies that result in a proposed solution to the
new problem. Bransford and Stein (1984) suggest that if successful this outcome indicates that the participants were exhibiting expert-like problem-solving behaviour. This outcome supports the argument of Robertson (2001) that this activity is an indication that the problem-solver is Semantically Rich. However, this expert-like problem-solving behaviour was not maintained by the participants in all areas of the design challenges. Antonietti (2001) claims that when the transfer of previously learnt and relevant knowledge and skills is exhausted, or the problem-solver is no longer able to draw an analogy between what was previously learnt and the new or novel problem domain or problem type, the problem-solver reverts to novice-like problem-solving behaviour and employs strategies such as trial-and-error to solve the new problem or problem type. It is argued that this is due to their semantically lean position within the new domain or problem type.

During Studies 1 and 2 all participants deployed high numbers of Executive Control procedures which supports the argument of Green (1989) that problem-solvers who rely on trial-and-error problem-solving strategies need to evaluate frequently, re-evaluate and modify their solutions to a problem. In addition, the participants deployed low numbers of Generation procedures which is interpreted as indicating that they possessed a shallow depth of knowledge in the domain and lacked experience of the problem type. However, in both studies the participants utilised physical artefacts in the problem-solving process.

In both studies the participants were given a number of information handouts and were asked to fill in the missing details of the problems solving event such as: what was the product like in the past? or: list the Problem Objects; however, the participants were not required to use the materials provided such as the paper and pencils to record their problem-solving activities. This was; however, the outcome. In all cases the participants chose to use these artefacts to help them solve both design challenges. Zhang and Norman (1994) argue that using physical artefacts transfers aspects of the cognitive process of problem-solving into the physical world and as a result makes problem-solving easier. Green contends that this process shows that the problem-solvers are developing an information system which records problem-solving events which allow certain problem-solving operations to be performed. Payne (2001) believes that the strategy alters the internal memory trace of the problem and transfers
the data to an external recording device or system such as paper, thereby allowing the problem-solver to retrieve the information easily and at any time. Payne (2001) argues that introducing physical artefacts into the problem-solving process in this manner redraws the boundaries of the problem to include strategies that reduce the cognitive load of the problem-solver.

The expert-like problem-solving behaviour exhibited by the participants when they were exploring the constraints and attributes of the problems conflicts with their lack of knowledge and or experience in the problem domain and problem type which indicates that they were *Semantically Lean* (Robertson, 2001, 17) and therefore exhibited the traits of novice-like problem-solvers. It is argued in this thesis that although a problem-solver may be considered an expert in one particular problem domain or problem type this does not qualify the problem-solver as an expert problem-solver in all problem domains or problem types. Further, it is argued that problem-solvers use a combination of both expert-like and novice-like problem-solving procedures and strategies when engaged in solving the same complex technological problem.

It is argued in this thesis that a new definition for an expert-like problem-solver should be considered. It is proposed that for a problem-solver to be seen as expert-like in a problem domain or problem type, a combination of prior knowledge and experience and cognitive procedures is required. In addition, it is argued that the expert-like problem-solver’s success depends on a number of factors including: (a) the problem-solver’s depth of knowledge, expertise and experience in a problem domain; (b) their depth of knowledge, expertise and experience of a problem type; (c) their ability to recognise similarities between the previous problems and new problems and their capacity to draw analogies between the two problems; and (d), their capability to transfer problem-solving strategies, knowledge, skills and experience learnt from previous problem-solving events to new or novel problem domains and problem types. However, if the same expert-like problem-solver is confronted with a new or unfamiliar problem domain or problem type where they are no longer able to perform such cognitive procedures as mentioned above and the transfer of prior knowledge and experience is exhausted, then they are no longer considered an expert-like problem-solver but rather a novice-like problem-solver and, as a result, begin
developing a new understanding of the problem domain and problem type and the knowledge and experience needed to solve such problems.

When the outcomes and the trial-and-error strategies employed by the participants of Study 1 are compared with the structured ASIT problem-solving strategy of Study 2, it appears that ASIT is able to compensate for the lack of transfer from the known to the unknown by forcing the problem-solver to deploy significant numbers of Exploration procedures to guide their activities. This strategy appears to result in the deployment of a controlled trial-and-error strategy. ASIT achieves this by forcing the problem-solver to compare the advantages or disadvantages of each of the attributes and elements contained within the Problem World. However, further analysis reveals that although ASIT controls the trial-and-error strategy it also directs the problem-solver’s course of action.

Despite all participants generating plausible solutions to the ASIT design challenge in Study 2, it was not without significant cognitive load. This was demonstrated by the difficulties that the participants encountered when applying the ASIT problem-solving process. This cognitive load was realised by the deployment of a significant number of Segments that were unable to be coded due to their ambiguous nature. It is argued that these cognitive difficulties may be the result of the structured nature of ASIT as it uses a number of preset rules that must be applied. Horowitz (2001) states these rules minimise the number of actions required to solve technological problems. Payne (2001) notes that it is logical to assume that problem-solvers prefer to use a structured problem-solving approach and plan before acting so as to reduce the number of actions required to solve a problem. Green (1989) believes that this strategy is not intuitive as people prefer an opportunistic problem-solving strategy such as trial-and-error rather than any structured strategies such as top-down development.

In addition, it is argued that ASIT helps to overcome the cognitive phenomenon referred to as functional fixedness and rigidity. The results of Studies 1 and 2 indicate that all participants generated a greater number of Goal Switching [SW] procedures during Study 1 than in Study 2. This is interpreted as indicating that ASIT directs the problem-solver to deploy these procedures so that they explore all of the elements within the problem and therefore overcome the tendency of the problem-solver to
remain fixated on one particular direction, element, and groups of elements from which to generate a plausible solution. Horowitz (2001) argues that this ASIT strategy improves the possibility of the problem-solver generating a plausible solution to the problem from the elements contained within the problem therefore simplifying the problem and the solution.

Kimbell et al. (2004) found that by … taking away the need to think about how they [the students] will organise their work, they are empowered to concentrate [on their goal and] on the ideas that drive their designing (Kimbell et al., 2004, 62). It is argued that a similar outcome resulted in Study 2 when the ASIT problem-solving process was applied. It appears that ASIT closely guided the participants’ attention and cognitive processes toward achieving the final goal of the design challenge while relieving them of the need to consider which strategies to use to achieve this goal. As a result, the majority of the Generation procedures the participants deployed in Study 2 were associated with creating plausible solutions to the design challenge rather than correcting numerous design and manufacturing faults or errors as in Study 1.
CHAPTER 7

CONCLUSIONS

7 INTRODUCTION

This thesis examines two related issues. The first is the nature of technological problems and the ways in which people solve them. It is argued that technological problems are complex and ill-defined and require specific strategies for their resolution. The second issue is the way in which pre-service Technology teachers solve technological problems and the strategies and pedagogical tools they use to solve. It is argued that currently, there is a lack of knowledge about strategies for solving technological problems and of the related strategies for teaching technological problem-solving in schools.

This thesis contributes to theory by proposing a more refined approach to the resolution of complex technological problems. In addition, the thesis contributes to theory concerned with the use of heuristics in complex problem-solving by advancing specific applications for problem-solving strategies. Finally, this thesis contributes to knowledge of the role of specific problem-solving systems of technological problem-solving performance by pre-service Technology teachers.

A number of predictions have been made about the way pre-service Technology teachers solve technological problems and their utilisation of problem-solving strategies. Two studies were undertaken as part of this thesis. They are reported as Study 1 and Study 2. Study 1 examined the way in which third year pre-service Technology teachers solved a complex technological problem using a free choice of problem-solving strategy, while Study 2 examined the way the same students involved in Study 1 solved a different, complex technological problem where the students were required to use the ASIT problem-solving strategy.

This chapter is structured in the following way. Firstly predictions synthesised from theory and detailed in Chapters 2 and 3 are reviewed. Secondly, findings from the two studies reported in Chapters 5 and 6 are summarised. Then the contribution of
the thesis to theory and practice is summarised and finally, suggestions for further research proposed.

7.1 THEORY IN OUTLINE

The resolution of complex technological problems is one that can be examined using information processing theory (Newell and Simon, 1972), within cognitive theory (Anderson, 1993). Technological problems (sometimes described as design problems) represent a particular kind of problem that is different to many problems that have been the subject of research.

Technological problems are conceptualised in terms of a synthesis of Newell and Simon’s (1972) model, Middleton’s (1998) modification of that model and Robertson’s (2001) characterisation of problem types that includes the problem-solver as one variable in determining the nature of problems. Thus it is argued that while technological problems can be conceptualised in terms of Newell and Simon’s model, they often require creative processes to achieve a solution and the knowledge of the problem-solver must be taken into account; hence the use of Middleton and Robertson’s theories.

Solving complex technological problems involves the deployment of three kinds of procedural knowledge (Anderson, 1993). The first of these is Generation, which is the creation of solutions, or moves towards the creation of solutions. The second kind of procedural knowledge is Exploration, which is the examination of those solutions generated. Both Generation and Exploration are guided by the third procedural knowledge type called Executive Control, which is concerned with the decisions about when to do what.

It is argued that when people solve problems, they use strategies to do so. When they are required to solve complex technological problems, they require specific strategies to advance, in particular, the generation process. Payne (2001) states that these strategies can be thought of as cognitive artefacts and include such physical artefacts as objects, pencil and paper sketches, to conventional drawings and graphs. It is argued here that ASIT can be considered as a cognitive artefact and therefore a
problem-solving strategy. Zhang and Norman (1994) claim that recording the various elements of the problem on paper enables the problem-solver to transfer aspects of the problem to the physical environment thereby making problem-solving easier.

Problem solving performance depends in part on the level of knowledge of the problem-solver (Simon, 1981). This is often framed within a comparison of the differences between the way in which novices and experts solve problems. It is argued here that unlike simple problem-solving, to solve complex technological problems successfully, requires not only knowledge of the content of the problems but knowledge of appropriate strategies for solving the kinds of problems encountered.

Wu et al. (1996) found that tertiary Technology students approached everyday problems in a similar manner to humanities students but approached technological problems differently from humanities students. It is argued here that to solve complex technological problems requires both a confident attitude to the problem-solving process together with appropriate problem-solving strategies and domain knowledge.

It is argued that for technological problem-solving success the problem-solver needs domain knowledge and strategies that are appropriate for the problem being solved. There are two kinds of strategies that appear in the research literature. The first are individual strategies such as analogical thinking Antonietti (2001) and the second are problem-solving systems that combine a number of strategies to improve the likelihood that the problem will be solved successfully such as TRIZ (Altshuller, 1990) and ASIT (Horowitz, 2001).

TRIZ is a problem-solving system that developed for invention in engineering within the former Soviet Union (Kaplan, 1996). The TRIZ system requires the problem-solver to employ a range of quite specific strategies that TRIZ proponents argue will lead to a solution of the problem. However, TRIZ has been found to be too specifically oriented to engineering problems and a system, derived from TRIZ, called ASIT has been developed (Malkin and Malkin, 2003-2004) that is believed to have wider applicability to problem-solving and in particular, complex technological problem-solving. It is argued here that ASIT represents a set of strategies pre-service Technology teachers can use to solve problems.
In changing from directed teaching methods to one based on problem-solving, Technology teachers have experienced difficulty in developing appropriate strategies for solving design problems and in helping their students to solve them (Middleton, 2003). In part this is the result of an imbalance in terms of age with most Technology teachers having had teacher training at a time when the focus was on directed teaching methods.

The difficulty is also caused by confusion between process and content (Zuga and Bjorkquist, 1989), where teachers regard the inclusion of new technologies in the form of computer tools or equipment as all that is required to develop contemporary Technology Education programs, rather than including design challenges based around responding to a Technology design brief. It is argued that in these circumstances, pre-service Technology teachers need specific, identifiable problem-solving strategies for themselves and to use as pedagogic tools within school settings.

The nature of the guidance provided to student technological problem-solvers and the effect different levels of guidance had on problem-solving performance (Kimbell, 2004) was examined. It is argued in this thesis that more guided systems of problem-solving compensated for the lack of knowledge and experience of the problem-solver by forcing them to undertake a managed process of exploration, controlled trial-and-error strategies and the deployment of fewer fruitless Generation procedures. These strategies resulted in a problem-solving approach that is more algorithmic in nature rather than heuristic in approach. More open approaches; however, produce greater numbers of Generation procedures but as they are heuristic in nature they are no more likely to produce a positive outcome than the guided systems, nor do they create any less cognitive load for the problem-solver.

It is argued in Chapters 2 and 3 that when people solve technological problems, they are more successful when they employ strategies to improve the chances of the problems being solved. Success can be improved by the use of individual strategies such as creative cognitive approaches (Finke et al., 1992) and analogical reasoning (Antonietti, 2000) or through the use of systems such as TRIZ and ASIT.
7.2 RESEARCH QUESTIONS

The three questions being addressed in this thesis are:

1. What are complex technological problems?
2. How do people solve them technological problems?
3. What strategies for solving complex technological problems are used by pre-service technology teachers?

7.3 SUMMARY OF THE FINDINGS FROM CHAPTERS 5 AND 6

The results of Studies 1 and 2 illustrate the complexities of ill-defined technological problems and the cognitive and psychological intricacies of the technological problem-solver. The literature argues that problem-solvers who are adept at exploring, analysing, modifying and transferring knowledge and experience from previous encounters to a new problem or domain exhibit expert-like problem-solving behaviour. However, when the expert-like problem-solvers’ repertoire of skills and knowledge is exhausted and they are unable to complete the design challenge based on past experience the problem-solver is understood to be semantically lean and viewed as exhibiting novice-like problem-solving behaviour. As a result of the analysis in Studies 1 and 2 and the interpretation of the cognitive and psychological literature, it is argued that technological problem-solvers when solving new problem types in domains that are unknown or less familiar to them, exhibit an interwoven combination of the characteristics of both novice and expert-like problem-solvers when solving the same ill-defined technological problem.

The strategy adopted by the technological problem-solver is dependent upon whether the problem-solver is an expert or a novice in the problem domain or problem type. The success of the strategy adopted is limited by the problem-solver’s previous knowledge and experience of the problem domain or problem type and once their limit of expertise is reached a different strategy needs to be employed, usually a novice-like problem-solving strategy such as trial-and-error. This is where ASIT is of benefit, as it compensates for the problem-solvers lack of prior knowledge, experience and expertise and reduces the number of unproductive cognitive procedures deployed by the problem-solver. If the problem-solver is a novice in the problem domain or
problem type, ASIT guides their problem-solving direction to a plausible solution in a more cognitively efficient manner than a trial-and-error approach. In addition, the strategies within ASIT help the problem-solver overcome cognitive phenomenon such as functional fixedness and as a result improve the possibility of the problem-solver generating a plausible solution to the problem. It is also argued that ASIT empowers the problem-solver to concentrate on their goals and the ideas that are driving their designing by organising their problem-solving activities.

7.4 CONTRIBUTION OF THE THESIS
This thesis is concerned with understanding the problem-solving heuristics and strategies that pre-service Technology teachers employ to solve technological problems. The intention is that a greater understanding of technological problem-solving and the strategies used to solve these problems will lead to the development of a new range of problem-solving teaching approaches and improved outcomes in the Technology Education classroom.

The contribution of this thesis is focused on four areas. Firstly, by performing two detailed studies into the manner in which pre-service Technology teachers solve complex design problems, this thesis adds to our understanding of structured and unstructured strategies and their impact on the deployment of cognitive procedures and the outcomes generated by those deployments.

Secondly, the thesis contributes to the development of an understanding of the effect of structured problem-solving strategies and the solutions generated when applied to ill-defined (Robertson, 2001) technological problems.

Thirdly, this thesis makes a contribution to our understanding of structured problem-solving strategies and the manner in which they direct the deployment of cognitive procedures and the generation of plausible solutions to ill-defined (Robertson, 2001) technological problems.

Fourthly, this thesis makes a contribution to teaching and learning by providing practical and theoretical ideas and concepts that can influence the development and
application of Technology teaching practice. As a result of this study, it is argued that systematic problem-solving strategies such as ASIT have a positive role to play in the development of technological problem-solving skills in the pre-service Technology teacher. However, it is suggested that these strategies need to be introduced into the Technology classroom as early as possible in the student’s academic career.

The contribution of this thesis to theory in terms of the impact of structured problem-solving strategies, such as ASIT, has implications beyond the Technology classroom and ill-defined (Robertson, 2001) technological problems. It is expected, therefore, that it may be possible to extend the findings of this thesis beyond the ill-defined (Robertson, 2001) problems of the Technology classroom to other aspects of education and curriculum.

7.5 SUGGESTIONS FOR FURTHER RESEARCH

The research reported in this thesis examined the technological problem-solving of three pre-service Technology teachers solving two separate complex design challenges. Studies 1 and 2 provided rich data and allowed useful conclusions to be drawn. These conclusions are limited; however, in terms of the ability to generalise the findings to other types of problem-solving in other domains. As a consequence there are a number of fruitful areas for further research.

The study reported on the ways in which participants solved two examples of technological problems. It was not possible to establish the extent to which the characteristics of these two problems contained elements common to technological problems in general or to particular types of technological problems. It would thus be useful to replicate the study using a wider range of problem types.

A limited number of participants were involved in the two studies. This was done because previous research by Middleton (1998) had established that when people engage in technological problem-solving they are engaging in a complex task that generates a rich data source that would provide sufficient material for a study of this kind. This proved to be the case. The three participants were selected on the basis that they represented the range within the student group in terms of knowledge, skill
and prior learning and experience. It would be useful; however, to replicate the study with a larger group of participants. However, for generalisations to be made of the findings of this research into technological problem-solving further studies that involve a larger number of participants and therefore, more replication will be necessary.

The participants in the study were able to employ their own choice of problem-solving strategy for Study 1 and were required to use a specific strategy (ASIT) for Study 2. This was done because the research literature indicated that these two approaches would provide the most relevant data to answer the research questions. This also proved to be the case. It is acknowledged; however, that it would be useful to follow up the present study with other studies where other strategies were employed.

The study sought to answer the questions of how pre-service Technology teachers solve complex technological problems and the use they made of general or specific strategies within activities that were a part of their teacher training. However, an important future aim of this area of study should be the ways in which Technology teachers employ problem-solving strategies as pedagogical tools to assist school students to solve technological problems.
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APPENDIX 1

Participant B Tape 1 - Lightbulb Packaging Design Challenge

T1 00:00
1. okay, so the next one is … [MO]
2. Okay, so this is … packaging [EC]
3. hey that's an idea [MO]
4. that's a good idea [EV]
5. that's a good idea I just thought of [EV]
6. ummm … so what have we got … [MO]
7. we've got the components of this design challenge are … [MO]
8. Okay [SW]
9. So … the challenge, the context is to illustrate the pros and cons … [GS]
10. I guess the design challenge, design the packaging [GS]
11. packaging is to be used as a lampshade [EA]
12. the inclusions [SW]
   i. (What are you doing here? - question from the research assistant)
13. Just breaking down the brief I guess into components that I can just glance at [SF]
14. so with the inclusions I can only use what's available [EC]
15. I need to … present and discuss the solution [GS]
16. Okay [?]
17. So … students critique [EA]
18. okay now I understand [EV]
19. all right so this is just writing down all the elements of a lightbulb and its packaging [EA]
20. so just filling out this sheet [SF]

T2 04:35
1. so the object is a lightbulb [EC]
2. ummm … [?]
3. its function is to provide light [EA]
4. lighting in different situations [EA]
5. ummm … [SW]
6. label the parts of the object [SF]
7. this is a screw type bulb instead of one of those … pin bulbs [EA]
8. so the … what would you call that, the base I guess [EA]
9. then there's the filament, element [EA]
10. I think it's the filament inside [EA]
11. and there is… [?]
12. I guess and [?]
13. and the materials [EA]
14. I think that's about it [EV]
15. So … what environment can you have it in [EC]
16. there's the home, business, tools, transport [EA]
17. home, business, tools, transport … ummm [EA]
18. entertainment [EA]
19. okay [SW]
20. so working through this [MO]
21. identifying it's past functions … [EA]
22. that would be very similar [EA]
23. ummm … [?]
24. that would be very much the same [EA]
25. so that would be the same [EA]

(what are you doing now? - question from the research assistant)
26. well going through this is … this sheet which is present past and future [SF]
27. in this top category of describing the object and its function it would still be called a lightbulb and it would still be used for illumination [EC]
28. so basically the same as that [EV]
29. hmmm … [?]
30. and I can't think of anything that … [RE]
31. The only … changes … in this column would need to be in future because whatever has been done here would be done there [SF]
32. so it would just follow on [MO]
33. so I guess it's the same [EV]

**T3 09:10**

1. ahhh … [SW]
2. label the parts [EC]
3. I think it would still be the … the bulb [EA]
4. there is … there is something … [?]
5. the insides have changed … slightly I think … ummm … from earlier versions [EA]
6. ummm … [?]
7. so we will just say less sophisticated internals [EA]
8. and I think also the … method of supplying power to it would have been made different [EA]
9. you wouldn't have that screw-bulb … I don't think [EA]
10. it would have been set up within the object I guess [EA]
11. so ummm … [?]
12. sigh … [SW]
13. what are we doing next … Environment [EC]
14. well lightbulbs are used in [EA]
15. be specific [EC]
16. ummm … [?]
17. so I … I guess like way back in the past lightbulbs were the, the substitution of candles [RE]
18. that might mean … [SW]
19. so at one point maybe only people who could afford … electricity could have lightbulbs [EA]
20. who could afford or access [EA]
21. ummm … [?]
22. okay … [SW]
23. describe the object in the future [EC]
24. the lightbulb will still be used to light stuff up [EA]
25. I don't know how that is going to change [EA]
26. So [?]
27. Okay [SW]
28. parts and components [EC]
29. ummm … well [?]
30. they are sort of present and now I guess just like … [SW]
31. moving away from the filament needing a vacuum [EA]
32. so you have got LED’s, long life bulbs [EA]
33. you've got [?]
34. ummm … [?]
35. ummm [?]
36. let's say [?]
37. phew [?]
38. what do you call it? [RE]
39. Ummm [?]
40. sigh [SW]
41. there is refining of the size [EA]
42. and … and … [?]

**T4 13:45**

1. of the size and the functionality I guess [EA]
2. the efficiency … [EA]
3. the size, function, the efficiency and lastly … the environment [EA]
4. ummm [?]
5. pretty much … [?]
6. let's say that's that, all right [EV]
7. that's it, I need to design packaging [GS]
8. packaging must also be used as the lampshade [GS]
9. okay so [?]
10. okay so with packaging the … the main … the main concept behind it is it must be a lampshade [GS]
11. so I guess we just look at a couple of lampshades [EA]
12. a couple of types of lampshades … circular, square [EA]
13. Oh, just a couple of different shapes I guess [EA]
14. that's pretty crap that one [EV]
15. so different types of lampshades you’ve also got … ones that … will encompass the lightbulb [EA]
16. so we have the fittings [EA]
17. I'm not sure if you could … [SW]
18. describe a lampshade [EC]
19. Ummm … any lampshade shapes can be used [EC]
20. So … we need to also look at [SW]
21. so I guess I could … [?]
22. Different ways would be … [?]
23. One, Two, three, four, five (number of solutions drawn on the page) [MO]
24. so in reference to … four [MO]
25. could the lightbulb… already be in place … within the packaging and not be taken out? [SY]
26. just packaging folded out around it [EA]
27. so could the bulb be … ready to fit [SY]
28. so could … [?]

T5 18:20

1. One, Two, three, four, five ummm … (number of solutions drawn on the page) [MO]
2. vary the shapes to suit different tastes [EA]
3. ummm [SW]
4. I guess … you would also need to consider … the, the stand or the socket that it is actually going to be … [SF]
5. if that's not … if that's not uniform that's not going to work [EV]
6. so they all need to … so they all need to have that light somewhere [EA]
7. ummm … [SW]
8. so what's available? [EA]
9. This one is crap [EV]
10. so that … must be uniform to connect [EA]
11. all right … [?]
12. so [?]
13. so the concept might [?]
14. ummm … [?]
going with the first … ummm design, the cone shape, that can be fairly easily replicated into packaging [TR]

so I guess you would [?]

so I need to reduce … reduce the size of the cone because you can't have actual size on the shelf so it got to be smaller [SY]

so what you could do with a packaging [EA]

1. it's pretty hard to draw [EV]
2. similar to this [?]
3. plastic top to display product [?]
4. ummm … [?]
5. so that is the shade for them [EA]
6. ummm … [SW]
7. so we'll go with number two now [EC]
8. ummm … [?]
9. I guess because it is square … you could possibly… [EA]
10. Similar to packaging that is used now [RE]
11. so that's there [?]
12. that's where the lampshade could be behind the object of the packaging [SY]
13. so … bulb [?]
14. so this could be the packaging for the bulb [SY]
15. so this keeps the sides up [SY]
16. packaging folds flat and out [SY]

(What are you doing now? A question from the research assistant)

17. Ummm … [?]
18. so just doing ummm … the flat pack [MO]
19. I think it would be the most transportable which would save [EA]
20. which would save a lot of the costs [EA]
21. you could stack more on the shelves [EA]
22. you could put more on the trucks [EA]
23. you could store them a lot easier [EA]
24. so that would possibly be [EA]
25. that would possibly be one of the most cost-effective ways instead of having it built in like this where [EA]
26. it's just you [SW]
27. you just fold it out and you screw it in [SY]
28. where you just take it out of the packaging there is less … there is less packaging in this one [EA]
29. but I think … [SW]
30. yeah [?]
31. the money spent on the packaging possibly save in the transport of the object because you can get so many more in [EA]
32. ummm … [?]

T7 26:50
1. so that's one [MO]
2. so now onto two [SW]
3. so let's go back here [SW]
4. ummm … [?]
5. okay so let's look at this one [MO]
6. no because … [SW]
7. so with this one you could have the advertising on the outside but when … it was folded out so it's on the shelf its … [EA]
8. In its folded out in a pattern [EA]
9. the design …the design would have sat on the inside [EA]
10. so … [?]
11. so … [?]
12. its folded out [EA]
13. you would have the advertising on the inside so you wouldn't see it any more [SY]
14. and the design would be on the outside and that design would probably be … displayed on the packaging [SY]
15. ummm … [?]
16. so I want to [SW]
17. let's go with … ummm … I guess … with the third product [MO]
18. I guess just … just … just these two designs [MO]
19. these two designs haven't really covered … [EA]
20. I haven't really talked about the stand or socket because that has to be like … [EC]
21. like the lampshade has to sit on the stand or the socket and so it's got to be uniform [EA]
22. so maybe including that in the product [EA]
23. but that's not really what they ask for [EC]
24. Right, well I am going to just start making one [GS]
25. so three is…so three can be that [MO]
26. so [?]
27. so here is one I made earlier [MO]
28. what a lampshade could possibly be [SY]
29. so stand up like that and put … and up … and put the lightbulb on top [EA]
30. so it could be interactive packaging that could be flat packed away [EA]
31. all right … so let's draw a picture of that [SF]
32. so this is like in 3-D [SF]
33. that's like a triangle [EA]
34. this sits on top [EA]
35. ummm [?]
36. like that [MO]

**T8 31:15**

1. so this [?]
2. okay [?]
3. and [?]
4. sigh … [?]
5. So that's like that [MO]
6. they can also just sit in the packaging [EA]
7. that could be quite funky [EV]
8. but it wouldn't actually work as a [EV]
9. it would be more of a … it would be more of a bulb stand and lampshade [EA]
10. so I will just include that with it [EA]
11. so now I think I will go for this one because it wants to be the best … [GS]
12. Right so [SW]
13. I am going to need a bit more material because I’ve got some basic shapes and I need to test … [EA]
14. and so that is … ummm [?]
15. okay [?]
16. so each side will have to be … [EA]
17. I need a ruler … a ruler [SF]
18. so this can divide this page in to the four sides of the lampshade [TR]
19. 21mm so that will come in … [SY]
20. So take six from each side [SY]

T9 35:20
1. all right … so now we have [SW]
2. so what we are going to need is to that … fold … fold over [SY]
3. so will be the … two … inside the folding [SY]
4. like that … that can go over the top [SY]
5. Right so let's get some tape [SF]
6. thank you Mr assistant (the research assistant passes the student some sticky tape) [?]
7. okay [?]
8. so what I am doing … is just putting the folds together …on the lampshade [SY]
9. these panels would obviously be … [MO]
10. I think you have most lampshades… most lampshades would be felt over a frame [RE]
11. which would be good [EV]
12. so this is just simulating that I guess [EA]
13. okay so now we have that [MO]
14. they would be, even then this is quite … quite large [EA]
15. I'm not sure how we [MO]
16. I will just fold that again [SY]
17. which can be done if we … crease it here like that … that reduces the sides [SY]
18. that will do [EV]

T10 39:55

1. something is happening here [MO]
2. We’re set now this is the lampshade put in the bulb which can then be flat packed away like that [SY]
3. ummm [?]
4. the lightbulb will sit like that [SY]
5. that will be effective for a package [EV]
6. okay let's colour this in [SF]
7. let's go with red and black circles [SY]
8. all right so far [EV]
9. so I guess that's the product that I want [EV]
10. that can be folded down [SY]
11. ummm [?]

(What are you doing now? A question from the research assistant)
12. I'm just doing a final product sheet so I guess how it has addressed the challenge, what it looks like ,what it will be doing [MO]

39:55 END of TAPE
Participant B Tape 2 - Brisbane Library Design Challenge (ASIT)

T1 00:00

1. ummm … [?]
2. I am just going to write down the tool types so that I can sort of remember them easier [SF]
3. so what I have put down here [MO]
4. ummm … [?]
5. I am just planning out each of the tools [SF]
6. Ummm … [?]
7. The example that was used with them … each time [MO]
8. so that will probably just jog my memory cause… [MO]
9. I think we have done most of them [MO]
10. Ummm … and with each there is the general… [MO]
11. In each of them you identify the problem world, the wanted action then you insert the tool out of the list and then you develop the idea [EC]
12. Ummm … [?]
13. So I am just going through ummm… [SF]

T2 03:41

1. Going over each … [MO]
2. What each of them ummm … [MO]
3. I guess what's in them [MO]
4. So… I guess with the unification it's just combining the elements you've got to see if you can solve the problem [EC]
5. I am not sure if it's drawing on much else other than what is in the problem [SF]
6. I am not sure if it is bringing in any external factors [SF]
7. I think it is just working with what you have [SF]
8. I will just jot that down … [MO]
9. working with what you've got and nothing else [EC]
10. Ummm … [SW]
11. Multiplication [EC]
12. Ummm … [?]
13. So just move on to multiplication [SF]
14. I think I got that one down [MO]
15. Ummm … [SW]
16. Skip through to where it says [SF]
17. multiplication is a new object of the same kind … as the chosen object,
   will do the same action which is the wanted action [EC]
18. so … Multiplication is using the same or similar object … as they
   chosen object [EC]
19. Ummm … [SW]
20. Division is next [SF]
21. which is… [MO]
22. ummm … [?]
23. Taking an object I guess, which is the problem or the challenge is
   revolving around and splitting it up into its parts [EC]
24. Ummm … [?]
25. Parts or sub objects [EC]
26. and I think ,I think division is splitting up … [RE]
27. seeing if you can bring in one of the parts [EC]
28. Ummm … [SW]
29. Breaking symmetry and that is … [SF]
30. breaking symmetry is similar to the division tool [SF]
31. so it usually would be a single object not a single environment [SF]
32. ummm … [?]
33. But that is not always the case [EC]
34. okay [?]
35. so … [SW]
36. you list all variables and the characteristics of the object … [EC]
37. and connect those to the problem that you are happy with … [EC]

T3 07:37
1. list is … [SW]
2. object removal … which I guess is pretty self-explanatory [MO]
3. I think that's … like [SF]
4. It seems to be playing off division and breaking symmetry [SF]
5. I am seeing if you can remove … [SF]
6. So you need to identify the components of the problem … [SF]
7. and then see if you can remove [SF]
8. see what needs to be removed to [SF]
9. ummm … [?]
10. see if it fixes the problem [SF]
11. all right … [MO]
12. so … that is that done [MO]
13. that is the basic rundown of all the tools [MO]
14. ummm … [SW]
15. and … our case study is something to do with the Brisbane library [EC]
16. so it's … [?]
17. ummm … [?]
18. the Brisbane library needs to move all of its books from the old town library to the new town library [EC]
19. so … [?]
20. ummm … [?]
21. I am going to do this as a graphic because it might help me [SF]
22. so … old library [EA]
23. so … new library [EA]
24. however the library only has a budget of $50,000 to the books and the estimates from the moving company exceed the budget [EA]
25. okay [MO]
26. so then we've got old to new [EA]
27. books that we are moving [EA]
28. ummm … [SW]
29. so just jot down some more factors [SF]
30. so … the object is $50,000 [EA]
31. ummm … [?]
32. the quoted costs … costs exceed … the budget amount [EA]
33. okay … [MO]
34. so … closed world conditions [EC]
35. the conditions of the closed world and qualitative change [EC]
36. the closed world [EC]
37. so that's just … [?]
38. next section [SW]
39. the problem that we are facing is [EC]
40. ummm … [SW]
41. so we have got the two types, closed world and change [EC]

1. ummm … [SW]
2. so … this will be a sheet that I will refer to throughout solving the problems [SF]
3. it's just got the basic information that I would need [MO]
4. so … I told … [SW]
5. so … I can come back and refer to my problem-solving tools [SF]
6. in the middle we've got [SW]
7. that's the visual of the brief with all the major information [MO]
8. ummm … [SW]
9. and I am just continuing to break down the brief into all its sections [SF]
10. so there are a couple of types here [SF]
11. the closed world [EC]
12. means no new types of objects can be bought in [EC]
13. so in the closed world I can use what's here and … [EA]
14. so I will just jot these down first [MO]
15. no new types …can be introduced… [EC]
16. and qualitative change means that … [EC]
17. Qualitative change conditions [EC]
18. the relationship between the undesired side-effect [EC]
19. okay … [?]
20. so … [?]
21. so … [?]
22. okay … [?]
23. so … [?]
24. that's the relationship between … the relationship between … [SW]
25. so simple problem statement [EA]
26. we don't have enough money to move all our books [EC]
27. there is nothing creative about our problem statement [EV]
28. ummm [SW]
29. simple solution statement to move the books [GS]
30. okay … [SW]
31. so next is just … running through the sheet [SF]
32. so that is pretty much done [EV]
33. that's what it wants and what I can use [EC]
34. so just running through all these [SF]
35. ummm … [SW]
36. dot points it's got here [SF]
37. so … [SW]
38. problem objects [EC]
39. so the problem objects in this case would be books need to be moved [EC]
40. ummm … [?]
41. let me just jump back to this one to check if it's got … any definition on the environmental objects [SW]

T5 14:19

1. I'm trying to class the problem objects and the environmental objects because sometimes I mixed it up when doing these in the past [SF]
2. So I think [MO]
3. although I can't remember [RE]
4. the environmental objects would be the … the transport, the books [EA]
5. ummm … [?]
6. the … possibly the quoted cost, which would affect … [EA]
7. Transport is part of the quoted cost [EA]
8. Books [EA]
9. Ummmm … [?]
10. environmental objects [EA]
11. I'm not sure where to put the budget under problem or environmental [MO]
12. Ummm … [?]
13. it lists them here [MO]
14. err … [?]
15. alright … [?]
16. Okay that makes more sense [MO]
17. the problem objects are what's ever is involved in the problem
environment is external like what affects [EC]
18. what has affects on those objects [EC]
19. so then I'll do that later [SW]
20. Points … budget, removers, library, distance to the new … [EA]
21. Alright [?]
22. ummm … [?]
23. so that's all you can work with here [MO]
24. so I think this is the library - closed world [EC]
25. so that's all the objects [MO]
26. nothing can be added [EC]
27. ummm … [SW]
28. let's just do a list [SF]

T6 18:00

1. employ staff, other people, locations [EA]
2. ummm … [?]
3. so just more environmental objects [MO]
4. so the affecting aspects of the problem [MO]
5. so there's the location and access to the new location [EA]
6. so it's still just plotting out everything involved in the problem [MO]
7. not really having started on trying to solve it yet [MO]
8. so that's … so that's good [EV]
9. solution world [SW]
10. err … [?]
11. okay … [?]
12. so this is … the problem world so far [MO]
13. so no solution [MO]
14. this is just what we found and working off a … [MO]
15. ummm … [?]
16. I think this is … [MO]
17. I think we should consider both of those the closed world and the qualitative change in the problem [SF]
18. So … [?]
19. Ummm … [?]
20. so I think I will just … [SW]
21. So that is a further breakdown that [MO]
22. what I can do now is … try … try and list the different tools … and … what they involve? [SY]
23. I will just grab this paper back for a sec’ [MO]
24. so just working off all the … ummm … the steps there … [SF]
25. So we have got … [MO]
26. Ummm … [?]
27. err … [SW]
28. Problem world [EC]
29. Wanted Action … [EC]
30. So … [?]
31. Books, to move the books … to move the books … [EA]
32. yeah … [?]
33. with the budget that they have [EA]
34. ummm … [SW]
35. So the tool goes in there … [SF]
36. So this is basically a step by step sought of process [MO]
37. Then the ideation or the development of the idea [SF]
38. all right [MO]

T7 21:01
1. so may as well … [SW]
2. so let’s see what we can do with Unification [SF]
3. ahhh … [?]
4. so we have got unification [SF]
5. so we need to… [MO]
6. ahhh … [?]
7. We need to combine all of the objects? [SF]
8. So unification is similar to the closed world in that you can't bring anything else in [EA]
9. ummm … [?]
10. so we have two work with what we have got [EA]
11. Ummm … [?]
12. God … [?]
13. so I guess … [?]
14. so I suppose we would have to … [MO]
15. ummm … [?]
16. We could maybe try and … [MO]
17. Maybe list as many as possible [SF]
18. the located budget [EA]
19. so that … then…$50,000 is used up [EA]
20. so if we do that we would be … [MO]
21. I don't know … a combination of the budget [SF]

T8 24:42

1. the movers, the books [SF]
2. so $50,000 [EC]
3. I guess these are just problems with this type … ummm … with this … ummm … attempt at solving the problem [MO]
4. so the money is used up [MO]
5. ummm … [SW]
6. the books are still left over which means the new library can't be opened because there are…not enough books in it [SF]
7. cannot … [SW]
8. cannot function effectively [EA]
9. right … [?]
10. so I might leave Unification and try a different … [SW]
11. ummm … [SW]
12. I might come back to Unification [EC]
13. Multiplication [SF]
14. Ummm … [?]
15. So in multiplication you can bring in the same or similar objects [EC]
16. what we could do … is multiply the funds [SY]
17. They… are one of the underlying problems [MO]
18. so maybe we could try and raise more … raise money [SY]
19. this could be done through … fundraising events [SY]
20. Ummm … [SW]
21. So Community [SF]
22. Community … they could ask for donations [SY]
23. Ahhh … [?]
24. The … the city itself [EA]
25. because it is the … [EA]
26. I guess because it is the Brisbane library which is part of … the
   Brisbane City Council … [EC]
27. I guess so [MO]

T9 28:23

1. so they could request more money from the city council or … [SY]
2. Multiplication [SW]
3. multiplication of movers [EA]
4. ummm … [?]
5. so they could … ask for volunteers to help move the books [SY]
6. ummm … [?]
7. ask volunteers if they could … [SF]
8. Someone I guess … [MO]
9. New movers … [EA]
10. I guess so [?]
11. ask volunteers [EA]
12. ahhh … [?]
13. use … use friends, friends and family … to move the books [SY]
14. ask staff … could move the books themselves [SY]
15. ummm … [SW]
16. the books … [EA]
17. You can't really multiply because that would cause more of a problem
   [SF]
18. there are too many aspects of multiplication I guess [MO]
19. the distance you can't multiply [SF]
20. we can't multiply the library [SF]
21. okay [?]
22. so let's try the next one [SW]
23. Division, division [MO]
24. divide the objects [EA]
25. ummm … [?]
26. so what aspects? [MO]
27. I am not sure if we can bring new objects into Division [EA]
28. Okay [?]
29. so that's [?]
30. so Division includes … [EC]
31. Time scale [SW]
32. so I guess we would have to make up… a time scale of events I guess [GS]
33. So … [?]
34. we go … [?]
35. money [EA]
36. ummm … [?]

T10 31:24
1. Move the books [EA]
2. okay … [?]
3. movers … new library [EA]
4. hmmm … [SW]
5. so if there was a time scale you could see how much time they had …4 to 6 months to do it in [SF]
6. okay so … [SW]
7. so this division is about … ummm … moving things around [EC]
8. there is no more leeway because there has to be a start and end point [EA]
9. old is one point and new is the end point [EA]
10. so the only … factors in between…are … [SF]
11. Move the books … movers [EA]
12. which could be … which could be done … either before the other [SF]
13. Ahhh … [?]
14. so … I might move on from division [SW]
15. I can't really think of anything [MO]
16. so maybe look at Symmetry [SW]
17. breaking symmetry [EA]
18. this characteristic is very … [SW]
19. So I guess I will list all the objects here and … which is … budget, 
   movers, books, library and new … [EA]
20. list characteristics of the various elements [EA]
21. I didn't leave enough room [MO]
22. so move … [SW]
23. Okay [?]
24. right [?]
25. budget restricted to $50,000 [EA]
26. movers … [EA]
27. sigh … [?]
28. This is between libraries [EA]
29. the two factors are the movers they will only take what they are paid
   for [EA]
30. okay [?]
31. ummm … [?]
32. I am just try to get a clear picture of what I am going to break
   symmetry into [MO]
33. at this stage are not entirely sure what's … [MO]
34. so what's … [?]
35. Select an object that would normally be a problem object [EC]
36. Environmental [EA]
37. to do this create a list of variables or characteristics [SF]
38. in different places the books will have different values [EA]
39. I guess it just wants to solve individual … [SW]
40. let's see if we can … [SW]
41. So let's see if we can put ideas towards the individual sections of the problem … [SF]

31:24 END of TAPE
APPENDIX 2

Participant G Tape 1 - Lightbulb Packaging Design Challenge

T1 00:00

1. Ummm … [?]
2. Sigh … [?]
3. in the current state it is probably going to be made the same but if we
   look to things like LED’s … ummm … lighting systems [EC]
4. ummm … [?]
5. the function will remain the same [EC]
6. Label the parts that will assist it to carry out … [SF]
7. ummm [?]
8. LED, Diode [EA]
9. ummm [?]
10. ummm [?]
11. circuitry … [EA]
12. ummm … [?]
13. resister, resistor, power-supply same as current … [EA]
14. ummm … [SW]
15. Again looking how far forward depending on the direction of human
    evolution and travels [SF]
16. Ummm … [?]
17. same as current traditional environments may exist depending on
   technology revolution [SF]
18. cool [EV]
19. Now your challenge … [MO]
20. now that we have examined the product in its past, present and future
   possible contexts, the design challenge looks at issues associated with
   solving sustainability and packaging design challenges its goal is to
   demonstrate the various elements associated with teaching design and
   problem-solving in a high school environment. [EC]
21. Okay [MO]
1. Students are provided with a selection of materials. Your design challenge is to design and make packaging for a light bulb that can be used as a lampshade, light shade for the same bulb. Students are provided with a selection of materials. [EC]

2. Thinking, thinking, thinking … [MO]

3. looking at the different types of materials we have this solution … [EA]

4. ummm … [?]

5. ummm … [?]

6. let's look at starting by doing a few sketches here [SF]

7. so we have got our… we have got a light bulb … [EA]

8. that is a light bulb, not a very good sketch [EV]

9. inability … [?]

10. ummm … [?]

11. ummm (sketching) … [?]

12. it goes into a socket which is connected to a power-supply [EA]

13. ummm … [?]

14. in doing so we need to … [MO]

15. lampshade is used to … ummm … channel lights … [EA]

16. ummm [?]

17. while protecting …[SW]

18. while in a determined direction … [EA]

19. not sure why I'm writing in pink [?]

20. in a determined direction and prevent lights …[EA]

21. ummm … [?]

22. going in other directions or unwanted directions [EA]

23. Looking at materials [SW]

24. Ummm … [?]

25. materials we have cardboard, paper … [EC]

26. ummm … [?]

27. sticky tape, blue TAC stapler pens, scissors, etc glue … [EC]

28. ummm … [?]

29. with the materials defined [MO]
30. looking, looking … [MO]
31. ummm … [?]
32. at what we need to achieve [GS]
33. We need to achieve packaging … [GS]
34. ummm … [?]
35. that doubles as a light shade [GS]
36. okay, so … [?]
37. with that in mind we need to define some of the possible solutions [SF]

**T3 08:20**

1. Prevent bulb being broken being … ummm … broken during travel … transport [GS]
2. Ummm … [?]
3. provide lighting direction [GS]
4. Ummm … [?]
5. it needs to not be … ummm … not be, not be a conductor due to an environment of application [GS]
6. okay [?]
7. ummm … [?]
8. I'm starting to think that we need to provide … that we need to provide … ummm … transport safety … [GS]
9. ummm [?]
10. as we go forward we need to provide transport safety [GS]
11. We could probably use some paper in a net that folds into a box that then folds into a shade [GS]
12. Ummm … [?]
13. we could … look to … ummm … to one thing is to provide a transport solution [GS]
14. ummm … [?]
15. provide a solution that works in both the transport in the packaging stage and as a light shade [GS]
16. ummm … [?]
17. so my first idea here is to look at something along the lines of a net [SF]
18. I mean current bulbs are stored in a box which is then thrown out [RE]
19. Ummm … [?]  
20. If we could think about how that box could be used better … [SF]  
21. ummm [?]  
22. and integrated to provide a double challenge of … ummm …  
   packaging and a shade so we don't end up where we started with …  
   [EC]  
23. So with that in mind I will probably start with something looking  
   towards … [SF]  
24. something … [MO]  
25. shade [EA]  
26. along the idea of a net the net shape of the box then folds into the  
   shape required. [GS]  
27. Traditionally the lampshade would be … ummm … semicircle or  
   semi-sphere but there is no design proviso for the shape required. [EC]  
28. So working from a net who doesn't need to be … ummm … of that  
   particular shade … [SF]  
29. ummm … [?]

T4 12:30

1. with a hole punched in the middle it would be able to … [SY]  
2. ummm … [?]  
3. sorry … with a hole the screw base could fit through … [TR]  
4. ummm … [?]  
5. Which would when unfolded would provide a lampshade technique or  
   a lamp shade style [SY]  
6. Ummm …  
7. I don't think they chose the right guy to do this given that I am a bit of  
   a cripple (student has a broken arm). [SW]  
8. Something along those lines … [SF]  
9. ummm … [?]  
10. this is going towards just establishing what a possible lampshade might  
    look like … kind of like a prototyping idea [SF]  
11. ummm … [?]
12. so … if the box had maybe a hole in the lid the lampshade the … [SY]
13. little bit of ideation [SF]
14. we could make a lampshade look … [MO]
15. to be able to be folded out from the box in which the lamp shade is transported in [SY]
16. so one thing the design brief doesn't give us is all the context [EC]
17. it doesn't give us is the shape or the direction of the lighting needs to be directed into [EC]
18. so would we make the assumption that the light just needs to be shaded so as not to be waste energy [GS]
19. so I put direction just in a downward direction. [GS]
20. So if we were to go with something like that how would we then make that into a box? [MO]
21. Will go to a little bit of basic graphics here [SW]
22. the net for a box is something like that … [MO]
23. ummm … [?] 
24. sorry about that [SW]
25. that one was not the greatest idea [EV]
26. ummm … [?] 
27. does … [?] 
28. ummm … [SW]
29. this is testing my skill development here because I can't remember the net [RE]
30. I am thinking of the shade … [SF]
31. ummm … [?] 
32. being … [?] 
33. could also folded into a box [SY]
34. maybe concertinaing … [SY]
35. err … [?] 
36. edges that fold with a flip lid that the user could cut off and discard [SY]
37. not the best of my sustainable ideas [EV]
1. but I've got a gut feeling if I can remember it correctly that it will be something along the lines of … [RE]
2. we need to fold down one more time for structural strength [SY]
3. I have two to turn that … [SY]
4. how would that then …? [MO]
5. let's mark this out a little bit … [SF]
6. somewhere across there … [SF]
7. somewhere across there so they crossed the centre [SF]
8. so if we were to replace the lightbulb in like that [SY]
9. how would that then concertina up into the packaging? [MO]
10. the bulb could be inverted for storage so that packaging could technically have a hole in it that the screw bulb would fit into when it is screwed into its socket [SY]
11. ummm … [?]
12. like so [MO]
13. that could be screwed into the socket quite easily and the paper could work as an insulator [SY]
14. can paper be an insulator? [EA]
15. I can't remember [RE]
16. the beauty of this is that it is at a high school level … [SW]
17. ummm [?]
18. the question is how would the packaging …[EA]
19. how would that packaging work safely if it was to be inserted [EA]
20. if it was to be a severe design [EA]
21. how would it fold? [EA]
22. Let's see … [MO]
23. ummm [?]
24. what's the biggest diameter we will fit on there? [EA]
25. 10 cm? [EA]
26. I am still prototyping [MO]
27. I am looking at the possibility of turning the packaging in … [SF]
28. that the lightbulb is carried in into the … [EA]
29. ummm … [?]
30. into the lampshade [EA]
31. obviously sticking with the idea of a fairly sustainable product in paper
   recycle trees can be controlled … ummm … as it is being currently
   controlled [SW]
32. so we are just looking … [MO]
33. ummm [?]
34. about using this current design [EA]
35. probably the biggest shape that I could … ummm … fit … [EA]
36. ummm [?]
37. while using … [EA]
38. while having enough grain structure in the paper to allow it to stand up,
   something like that and … [SY]
39. ummm … [?]
40. the idea being here that we will fold … ummm … up into a shape that I
   said before [SY]

T6 20:50

1. my remembrance of the knowledge of nets in graphics is not as good as
   it used to be … [RE]
2. ummm [?]
3. as to how the lampshade could … ummm … be transformed from a
   fairly regular packaging that we see today into the lampshade as well
   [MO]
4. what we will do is give this a go … [GS]
5. ummm [?]
6. that can fall apart when we do it … [SY]
7. ummm [?]
8. something like this … [MO]
9. ummm … [?]
10. this is just to … [MO]
11. ummm … [?]
12. to deal with the paper falling apart due to the method of construction
    that I will use [SY]
13. it should also illustrate how close to the centre I didn't get that before (referring to the hole he just made the paper) [MO]

14. ummm … [?]

15. I'll just pop this one out … [SY]

16. ummm … [?]

17. this style and design [?]

18. whereas we use these storage … [SW]

19. we use the … sorry … the packaging to become part of the product is a fantastic sustainability idea … [GS]

20. ummm … [?]

21. reduce wastage [?]

22. err … [?]

23. and makes sure what we are buying is what we are actually getting [GS]

24. Ummm … [?]

25. less packaging equals err … greater value for money … [SY]

26. also hopefully with reduced impact on the environment [SY]

27. let's say something like that [SW]

28. taking into account the ideas of how this is going to fold up to become the packaging idea [SY]

29. so if we had something like that [SY]

30. I'm just going to ask my supervisor here to hold this here so that I can pop a hole through the middle due to a broken arm [SW]

31. so [?]

32. at this stage … [MO]

33. ummm … [?]

34. as I have said before my knowledge of my nets is absolutely terrible [EV]

35. ummm … [?]

36. if you have kids at school that is something you should probably be worried about [SW]

37. so [?]

38. if we were to bring that up …[SY]

39. and … [?]
1. take our lightbulb package unit like so … [SY]
2. I will tag it where it is where the lightbulb is down as I can see how it slightly too small [EA]
3. ummm … [?]
4. the idea being that is to come together … [EA]
5. that will need to go down like so [SY]
   i. (Interviewer asks ‘what are we trying to do here?’)
6. we are still trying to establish the net here to establish what shape we need to get [EA]
7. ummm … [?]
8. a semicircle or a multisided polygon … [EA]
9. ummm … [?]
10. to work as the … ummm … the light shade … [EA]
11. ummm [?]
12. unfortunately … ummm … I am going to concede that that net has failed terribly and I need I go back to an idea that I just had which is to start with a square in the middle with said hole in it [EV]
13. sigh … [?]
14. each of … [SW]
15. so essentially she is a square box [EA]
16. like so [MO]
17. each of these needs to concertina in for us to find said shape [EA]
18. so 1, 2, 3, 4, 5 … [MO]
19. ummm … [?]
20. essentially the lightbulb wouldn't have a top on it [SY]
21. the lightbulb packaging wouldn’t have a top on it due to the fact that the lightbulb would be inverted [EA]
22. ummm … [?]
23. or [SW]
24. it could have a top on it … [EA]
25. ummm … [?]
26. that would then fall to the underside to provide … [EA]
27. ummm … [?]
28. some great or greater thickness of the material and the light shade [EA]
29. ummm … [?]
30. thinking out loud … [MO]
31. sorry [SW]
32. I am not very good at thinking and learn … [EV]
33. ummm … [SW]
34. we are looking at a 10 cm or 100 millimetre lightbulb [EA]
35. ummm … [?]
36. so [?]
37. if we move that out to 120 mil’ [EA]
38. so we need … [SW]
39. ummm … [?]

T8 29:10

1. I have to start thinking about this net [GS]
2. Ummm … [?]
3. the reason the material is being folded is because of three … [EA]
4. ummm … [?]
5. to provide some structure [EA]
6. to provide some material where the paper is already a bit thin for what
   I originally … or what I would use in my own design solution outside
   of the University [EA]
7. you see I would probably use a heavy weight … ummm … card of
   some type [EA]
8. so I will have a look … [SW]
9. ummm … [?]
10. at probably … ummm … 124 mil’ [EA]
11. I am not going to lie and I am feeling a bit switched off here [SW]
12. Ummm …
13. ………. (long pause)
14. so we need a 10 x 10 or a 12 cm … [EA]
15. ummm …
16. base to provide sufficient material for when the sides are folded up
   [EA]
17. I am having an absolute shocker this isn't going anywhere near as planned [EV]
18. Ummm … [?]
19. …………… (long pause) [?]
20. So … [?]
21. the side up … [?]
22. thinking, thinking, … [MO]
23. just working out some … some measurements [SW]
24. this is actually a really good thing [EV]
25. this is something I would like to do with the kids [EV]
26. it's just that I am very switched off at the moment [EV]
27. ummm … [?]
28. mid-semester break is looking a little bit all too good right now [SW]
29. you can see the approximate centre there which is when the lightbulb is packaged will need to be the middle [EA]

T9 33:20

1. ummm … [?]
2. that will go over there something close to a centre line [SY]
3. ummm … [?]
4. this will work [EV]
5. okay [?]
6. that’s centre [MO]
7. so [?]
8. let's go say …. [SY]
9. that's 10 so let's go a 150mm in all directions that should give us our basic net [SY]
10. Chris Ralph could tell you that there is a bit of ‘GraphCom’ 1 coming back [SW]
11. Thinking out load if we could find a usable net [SF]
12. ummm …
13. this will be a good design solution that provides said packaging for the lamp [EV]
14. ummm … [?]
15. err … [?]
16. Ummm … [?]
17. still got a feeling that the sides are going to be a little bit too small but [EV]
18. ummm … [?]
19. wow … [?]
20. sigh [?]
21. my ability to measure here is certainly going to be called into question [EV]

**T10 37:30**

1. so … one thing I haven’t really taken into consideration here … errr … is the possible dangers associated with using a material such as paper around lighting [EA]
2. ummm … [?]
3. it may be the fire danger that has been increased … [EA]
4. ummm … [?]
5. which is something that will have to be taken into consideration before manufacturing this, but … ummm … but you would get that realistically [MO]
6. wow … [?]
7. sigh [?]
8. a little bit folding here and here [SY]
9. I really need to take into consideration the grain of the paper [SY]
10. this is a little difficult with a broken arm [SW]
11. okay [?]
12. so what we need to achieve … [MO]
13. we have achieved there is our … [MO]
14. we need to achieve a concertina effect in here to achieve … [GS]
15. I hope you appreciate this is a lot easier to achieve with two arms [SW]
16. if that will come up like that [SY]
17. I am just going to get my design assistant to help out so if you could hold that for me (Research assistant folds up the participants design solution) [SW]
18. thank you [?]
19. if you can do all four for me that would be great [SY]
20. so what we can see, that now is the desired effect [EV]

37:30 END OF TAPE
Participant G Tape 2 - Brisbane Library Design Challenge (ASIT)

T1 00:00

1. So these are constraints as seen in the design brief [EC]
2. Closed World condition [EC]
3. Closed World means something along the lines of nothing can be bought in to it [RE]
4. so … no qualitative … [EA]
5. sigh … [?]
6. so … Closed world … [EC]
7. no new types of objects can be added [EA]
8. means Qualitative World examines changing the relationship between the undesired effect … [EC]
9. and … because of that affect worsening … [EC]
10. see the problem statement [SW]
11. we don't have enough money to move all our books [EA]
12. there is nothing creative [EV]
13. okay … [?]
14. see the problem statement [EC]
15. problem objects [EA]
16. list all object of the problem world [EC]
17. books, so now we are just defining the objects in the problem world in ASIT through the ASIT problem-solving technique [SY]
18. books … [EA]
19. we’ve got the old town library the new town library [EA]
20. we have a budget of $50,000 ummm … to move the books [EA]
21. and all the estimates the removals company … the removals company … [EA]
22. errr [?]
23. equals … [?]
24. errr [?]
25. greater than … [?]
26. okay so … [?]
27. let's have a look to see how … [SW]
28. so [?]
29. okay [?]

T2 04:23

1. what’s our problem? [EC]
2. its reasonably clear to see it … [MO]
3. so … library needs to move books [GS]
4. budget insufficient for removal [EC]
5. okay … [?]
6. what's our problem objects? [EC]
7. errr … [?]
8. our problem objects are books, budget, movers, library, distance to library [EA]
9. the environment objects [EC]
10. book borrowers, library staff, other people, streets and other vehicles on the streets [EA]
11. the whole idea of ASIT method is to check for solution directions which we would consider … [SY]
12. which are the ASIT tools we would use [SY]
13. okay [?]
14. errr … [?]
15. so … unification to bring it together [SW]
16. so now we are just examining the different techniques that we can use under the ASIT problem-solving technique [SF]
17. so … [?]
18. is to … [?]
19. Give me a definition of Unification … definition … [SF]
20. okay [?]
21. that's unification process … [SW]
22. I see that what we are coming up with pretty often prevents or … [SF]
23. as we move over to multiplication [SW]
24. multiplication was a key word here multiply [EC]
25. division [EC]
26. multiplication [EC]
27. division breaks symmetry [EC]

T3 08:06
1. object removal [EA]
2. see the object removal tool could be quite handy here because in addition to our two objects we are removing [SY]
3. in theory here we could be removing an object and moving it to the new library [SY]
4. ummm … [?]
5. as a way of overcoming of getting the books to the next location [SF]
6. breaking symmetry [EC]
7. dripping candles … [SW]
8. just looking for problems that have similar objects and similar issues to the one doing … [RE]
9. okay [?]
10. a little bit of ideation now of some possible solutions based on a little bit of early thinking … [RE]
11. ummm … [?]
12. borrowers borrow books … [EA]
13. they need to return the books … [EA]
14. the borrowers borrowed from old library returned to new library [EA]
15. leftover books [SW]
16. ummm … [?]
17. could be moved for X dollars maybe $50,000 dependent on this size [EA]
18. one problem is we don't have in the constraints … [EC]
19. it does not tell us any type of information about how many books could be moved ummm … for that $50,000 [EA]
20. so … that probably shows us that the problem is asking us to think a little bit deeper [SF]
21. so that the $50,000 would not be used at all [EA]
22. so … [?]
23. ummm … [?]
24. library, people other vehicles on the street … [EA]
25. looking at the environmental effects [EA]
26. maybe using public transport [EA]
27. Ummm … [?]
28. public transport [EA]
29. books could be given to travellers on certain routes [SY]
30. ummm … [?]
31. asked to drop off past … to drop off maybe [SW]
32. maybe the 50,000 could be used [SF]
33. ummm … [?]

T4 12:29

1. could be used to subsidise errr … fares … [EA]
2. how do you spell subsidise? [RE]
3. distance to the new library [EA]
4. ummm … [?]
5. book borrowers, library staff, budget insufficient ummm … library
   staff, streets [EA]
6. ummm … [?]
7. books budgets, movers [EA]
8. I’m just using these words to see what light bulbs switch on [RE]
9. it is a little left-field but how much … [SF]
10. how much is it to move the physical library [SF]
11. ummm … [?]
12. errr … [?]
13. library staff [SW]
14. unification [SW]
15. now that we have done … [SW]
16. now that I have made some early ideation let’s go through the and have
   a look at our physical … [SF]
17. at the actual ASIT tools to ummm … further build on or maybe ideate
   some new ASIT ideation [SF]
18. how could we … [SW]
19. the problem world … [EA]
20. one problem I am having is the fact that we have not used ASIT for so long … is that it is all a little still scrambled in my mind [RE]
21. determined the problem world … [EC]
22. got that … [MO]
23. determine the wanted action …[EC]
24. so now we will go back to our first piece of paper with our defining problem world [SW]
25. so remember the problem objects that’s all there is to it [RE]
26. so … [?]
27. let's start with the list of problem objects [EA]
28. that's all there is to it [MO]
29. it is a good idea to list them in descending order of importance the objects have in the problem [SY]

T5 16:12

1. I think this has been beautifully done for us so I will write them out again [EV]
2. Ummm … [?] 
3. that is all there is to it [MO]
4. defining the problem world … [EA]
5. problem world is over here … [EA]
6. it's determined [EA]
7. determine the wanted action [EA]
8. okay … [?]
9. at this stage we determine the action and may solve the problem [SF]
10. we will do this in two stages [SY]
11. determine the unwanted action [EA]
12. derives the wanted action from the definition of the unwanted phenomena [EA]
13. object A … object A … object A … [SW]
14. so … what could we say here? [MO]
15. Books have a … have a … have a … costly unwanted effect on budget [EA]
16. Ummm … [?]
17. determine the wanted action derived from [EA]
18. the definition the action must include [EA]
19. derive the unwanted action directly from the unwanted phenomena to help create the definition better to prevent object A acting on XYZ [SY]
20. To prevent the books from having a costly effect on the budget … [SF]
21. Sigh … [?]
22. The books … [EA]
23. So … (long pause) [SW]
24. Unification [EC]
25. so … [?]

T6 20:35

1. the books will prevent the cost increasing budget [EA]
2. the budget will prevent the cost increasing budget [EA]
3. the movers will prevent the cost increasing the budget [EA]
4. the library will prevent the cost increasing the budget [EA]
5. the distance to the library will prevent the cost increasing the budget [EA]
6. the borrowers will prevent the cost increasing the budget [EA]
7. the library staff will prevent the cost increasing the budget [EA]
8. other people will prevent the cost increasing the budget [EA]
9. the Street will prevent the cost increasing the budget [EA]
10. the vehicles on the street will prevent the cost increasing the budget [EA]
11. okay [?]
12. elaborating the idea … now [SF]
13. with those statements made we’ll … [SW]
14. let's break them out a little bit further to start to investigate how one of those might become a realistic solution [SY]
15. or … [SW]
16. some of those might become a realistic solution [SF]
17. so … the books will prevent the cost increasing the budget … [EA]
18. how could that happen? [SF]
19. Ummm … [?]
20. the books will prevent the cost increasing the budget [EA]
21. Err … [SW]
22. the books … the books … the books … [EA]
23. ummm … [?]
24. The books will prevent the budget … [EA]
25. the movers will prevent the budget … [EA]
26. I think there is really something to be had in the movers … in the
   movers and … [SF]
27. no … apologies … [SW]
28. the borrowers [EA]
29. I think there is really something in the book borrowers moving the
   books to the new location [SY]
30. it is simple it doesn't add anything in … [EV]
31. it's a process that is going to occur anyway … ummm … whether they
   had to come back to the original location or they had to go further …
   [EV]
32. ummm … [?]
33. or a new location [EA]

T7 24:18

1. the one realistic effect is … ummm … that for a lot of people it may
   mean more travel … ummm … that they are unwilling to make …
   [EV]
2. it may mean more travel … unwillingness to travel [EA]
3. on the flipside it may be … ummm more … [EA]
4. ummm [SW]
5. may be less travel ummm … and therefore more willingness [EA]
6. and in the event … in the event of a simple question by library staff as
   to willingness ummm … they may be asked to take more books [SY]
7. ummm … [?]
8. errr … [?]
9. not necessarily read just returned [EA]
10. just transported [EA]
11. ummm … [?]
12. ummm … [?]
13. errr … [?]
14. I think this is … this is actually quite a good solution due to ummm …
due to cost ummm … due to cost [EV]
15. ummm …[?]  
16. which is obviously a massive determining factor [EV]
17. ummm … [?]
18. it could possibly be used with other solutions to gain a full solution 
   [SY]
19. ummm … [?]
20. Distance to the library … [EA]
21. the library staff … [EA]
22. ummm … [?]
23. distance to the library … [EA]
24. ummm … [?]
25. short distance [EA]
26. may mean the $50,000 is better spent … ummm … on … ummm … library staff [EA]
27. or extra library staff being asked to act as Removalists [EA]
28. the money stays … [SW]
29. the money stays … ummm … in the library or with the employees of 
   the library [EA]
30. ummm … [?]
31. always dependent on how far this distance really is [EA]

**T8 28:01**

1. If it is a massive distance the effects might be lost on vehicles and the 
   amount of money it's going to cost the employees to move the books to 
   the library [EA]
2. ummm … [?]
3. but we are working towards a possible solution [GS]
4. So let's explore everything that we have … [SW]
5. ummm … [?]
6. let's look at the environmental effects [EC]
7. ummm …[?]
8. we have other people associated with the library … [EA]
9. volunteers [EA]
10. ummm … [?]
11. volunteers … [EA]
12. ummm … [?]
13. who may volunteer time and money [EA]
14. ummm … [?]
15. to assist move [EA]
16. ummm … [?]
17. additionally they may if distance is short … is short … they may read books for library [EA]
18. the other vehicles on the street is something I think maybe … [SF]
19. other vehicles on the street … [EA]
20. this needs to be explored … needs to be explored … [SF]
21. the library the Brisbane library government owned [EA]
22. ummm … [?]
23. the government also owns … [EA]
24. ummm … [?]
25. buses … [EA]
26. ummm … [?]
27. fleet of vehicles [EA]
28. ummm … [?]
29. additional government resources could be spent on the move … [EA]
30. ummm … [?]
31. that aren't … [SF]
32. ummm … [?]
33. subsidised bus fares in exchange for people dropping books off at new library [EA]

T9 31:24
1. … (long pause) [SW]
2. Let's have a look here multiplication [SW]
3. ummm … [?]
4. just go back to examining some … for ideas [SW]
5. ummm … [?]
6. ummm … [?]
7. multiplication really talks about … ummm … adding … [EA]
8. as much as I don't want to say it … adding … [EA]
9. ummm … [?]
10. additional [EA]
11. errr … [?]
12. parts to the solution but necessarily might be already existing [EC]
13. so in the case of the fish one [SW]
14. putting in bigger fish to make the smaller fish continually swim [SF]
15. the bigger fish chase the smaller fish [SF]
16. ummm … [?]
17. how could that be made to fit into the library situation? [SF]
18. got the books [EA]
19. got the budget [EA]
20. got the movers at the library [EA]
21. got the distance to the library [EA]
22. ummm … [?]
23. ummm [?]
24. the other staff [EA]
25. Could the … [?]
26. just getting these ideas out using the multiplication tool [SW]
27. budget be better utilised on attracting more borrowers [EA]
28. borrowers are multiplication [EA]
29. to facilitate moving books by the return system … [EA]
30. by the modified returns system seen earlier … [EA]
31. or derived earlier [MO]
32. ummm … [?]
33. derived earlier [MO]
34. Therefore multiplication … [SW]
35. therefore the returns … [SW]
36. the number of returns will be increased [EA]
37. ummm … [?]
38. will be all to move more books … [EA]
39. ummm …[?]
40. to the new location at … [SW]
41. within the $50,000 [EA]
42. ummm …[?]
43. Can more books be multiplied? [EA]
44. how will multiply more books help us? [EA]
45. Ummm …[?]
46. could … could … could the books … could the books be purchased …
   ummm … for cheaper than $50,000 at the new location? [EA]
47. is the cost of the move cheaper … errr … than … or more expensive
   than replacing the products at the other end? [EA]

T10 35:07

1. Could the books be purchased again at the new location? [EA]
2. ummm …[?]
3. maybe not an entirely realistic answer in the olden times but with the
digital age … [EV]
4. ummm …[?]
5. and a move away from physical hard copies of books could be more e-
   learning and Internet-based [SY]
6. ummm …[?]
7. databases that libraries provide … [SW]
8. could be done cheaper in the new location rather than physically
   moving the books [EA]
9. Ummm …[?]
10. digital age, e-learning [EA]
11. ummm …[?]
12. etc, etc[?]
13. probably not a realistic answer but definitely an answer from within the
   problem [EV]
14. ummm …[?]
15. ummm …[?]
could the budget be increased? [EA]
but we already said there is no money [EA]

Division … division, division, division [MO]
I think … I think this really relates to … ummm … to dividing [EA]
the dividing the number of books across the number of borrowers [SY]
I really think there is something in that [EV]
I think ummm … by … by spreading X number of books across Y
whereas simply asking them to Y +1 or you know sorry, X +1 [SY]
asking them to borrow a book or borrowing a book … a book plus
another or other two that they would not necessarily read and just
asking them to facilitate the drop-off at the new location. [SY]
I really think there is something in that … [EV]
borrowing a book plus another or two … ummm … to drop off at the
new location. [SY]

35:07 END of TAPE
APPENDIX 3

Participant P Tape 1 - Lightbulb Packaging Design Challenge

T1 00:00

1. Your challenge is to design and make packaging for a light bulb that can also be used as the light shade/lamp shade for the same light bulb. [EC]
2. Inclusions [EC]
3. Students are provided with a selection of materials and asked to work on the design challenge individually (this is not a team challenge). [EC]
4. At the end of the design challenge students are asked to present their solution and discuss the designing and making issues they encountered and how they were solved. [EC]
5. Students are encouraged to ask 'teacher' questions of the student presenting to draw out more information about their design solution. [EC]
6. You have 1 hour to complete the design challenge. [EC]
7. So what have we got? [EC]
8. Ummm … [?]
9. Do you want this on this one or this one? [EC]
10. (Supervisor-whatever suits you)
11. this is more easier to manage [EC]
12. okay [SW]
13. so … [?]
14. we need to … [EC]
15. Your design challenge … [EC]
16. Your challenge is to design/make [EC]
17. Ummm … [?]
18. Design a packet for [EC]
19. Can be used [EC]
20. … (long pause) [?]
21. Ummm … [?]
22. Make paper packaging that can also be used [EC]
23. that can also be used as a lampshade [EC]
24. right ummm … [SW]
25. bulb [EC]
26. ummm … [?]
27. size [EC]
28. materials used for making the box [EC]
29. ummm … [?]
30. ummm … [?]
31. … (long pause) [?]
32. Heat [EC]
33. insulation to prevent burning [EC]
34. ummm … [?]
35. monitors [EC]
36. ummm … [?]
37. ummm … [?]
38. What do we know about existing products? [SW]
39. Ummm … [?]
40. It's a new … [SW]
41. existing products [EC]
42. they are throwaway [EC]
43. existing products
44. ummm … [?]
45. ummm … [?]
46. card [EC]
47. Materials are … Card [EC]
48. is it corrugated card or is it straight card? [EC]
49. Ummm … [?]
50. Ok [MO]
51. Corrugated card/card [EC]
52. Ummm … [?]
53. Phew [?]
54. Ummm … [?]
55. Product information on it [EC]
56. Information [EC]
57. Ummm … [?]
58. Possibly recycled [EC]
59. Recycled … Paper [EC]
60. recycled card [EC]
61. ummm … [?]
62. … (long pause) [?]
63. Ummm … [?]
64. Phew [?]
65. Function [EC]
66. Function [EC]

**T2 04:34**

1. … (long pause) [?]
2. (research assistant asks ‘what are you thinking now?’)
3. Oh, I am just getting a couple of measurements that will float around in the back, in the back [SY]
4. Ummm … [?]
5. What else have we got here? [EC]
6. Right [SW]
7. One, describe the object and determine its function in the present [EC]
8. ahhh, it is no good asking me [EV]
9. ok [SW]
10. Two, label parts of the object which assist it in carrying out its function [EC]
11. pencil sharpener [SW]
12. that's all right is it missing? [?]
13. Describe the object [EC]
14. The object [EC]
15. describe the object [EC]
16. ummm … [?]
17. Describe the object and its function [EC]
18. it's a light [EA]
19. … (there is a long pause as Subject P writes down the answers to these questions on his assignment sheet) [EC]

20. Describe the object and how it carries out its function [EC]

21. Ummm … [?]

22. what is the name of this bulb? [EA]

23. Like what is it? [EA]

24. (Research assistant answers incandescent)

25. No, no, no the fitting [EA]

26. there is the … bayonet … [EC]

27. Just screw and the bayonet is the one with the two pins [EA]

28. screw thread [EA]

29. ummm … [?]

30. that’s a … filament with an ‘F’ [EA]

31. filament [EA]

32. ummm … [?]

33. Well it is in glass because it is a vacuum isn't it? [EA]

34. Ummm … [?]

35. The glass creates a vacuum [EA]

36. Ummm … [?]

37. Phew [?]

38. It is home brand, expensive! [SW]

39. Ummm … [?]

40. Ummm … [?]

41. … (long pause) [?]

42. Ummm … [?]

43. (research assistant asks ‘what are you thinking now?’)

44. Ummm … [?]

45. Just filling out these boxes (referring to the assignment sheet) [MO]

46. just making sure it all goes in together [MO]

47. name the environment in which the functions of the object take place… [EC]

48. name the environment? [EC]

49. household lighting [EA]

50. ummm … [?]
51. Lighting [EA]
52. Ummm … [?]
53. OK [?]

T3 09:08

1. … (there is a long pause as Subject P writes down the answers to these questions on his assignment sheet) [EC]
2. describe the object in terms of its function in the past [EC]
3. describe the object in terms of … [EC]
4. I wonder if that's [SW]
5. describe the object in terms of its function in the past [EC]
6. is this a spare [SW]
7. … (there is a long pause as Subject P writes down the answers to these questions on his assignment sheet) [EC]
8. Ummm … [?]
9. label parts of the object which assist it in carrying out its function in the past [EC]
10. as per part two [SW]
11. label parts of the object which assist it in carrying out its function in the past [EC]
12. … (long pause)
13. label parts of the object which assist it in carrying out its function in the past [EC]
14. ummm … [?]
15. … (long pause) [?]
16. label parts of the object which assist it in carrying out its function in the future [EC]
17. name the environment in which the function of the object is carried out [EC]
18. that, that, that … [?]
19. ummm … [?]
20. label parts of the object which assist it in carrying out its function in the future [EC]
21. name the environment in which the function of the object is carried out [EC]
22. like that? [EV]
23. ok [SW]
24. that, that, that … [?]
25. ummm … [?]
26. ok [?]
27. so [?]
28. design and make packaging for a light [GS]
29. phew [?]
30. ok [?]
31. What do we know about existing products? [EA]
32. Ummm [?]
33. existing products are a [EC]
34. ummm … [?] 
35. are a box type shape [EA]
36. they have … [SW]
37. Cut that from there and there and there [SF]
38. which will cut out that way [SF]
39. ummm … [?]
40. … (there is a long pause as Subject P draws a solution on his worksheet of paper) [EC]
41. I don't know how to start [EV]
42. Now [SW]
43. Ummm … [?]
44. Card, what's this here? [EA]
45. Ummm … [?]
46. That’s a … [SW]
47. Now …
48. Cut this here [SY]

T4 13:02

1. This here ummm … prevents light from leaving the package [SY]
2. Ummm … [SW]

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3. I think from memory there is one down in the bottom somewhere [RE]
4. Ummm … [SW]
5. There might be one on this side as well [EA]
6. something like that [EV]
7. phew … [?]
8. ummm … [?]
9. … (long pause) [?]
10. another possible box design [SW]
11. ummm … [?]
12. I think is a cylindrical tube like so and this top part up here is ummm concertinaed on itself [SY]
13. ummm … [?]
14. Top and bottom [EA]
15. So instead of square it is round [EA]
16. ummm … [?]
17. The light is inside there … it will open up [EA]
18. ummm … [?]
19. So it still has the right amount of … [EV]
20. It can be made out of recycled card and at the moment the throwaways [EA]
21. Protect, protect … the user [SW]
22. Ummm … [?]
23.Alright, if possible ummm ideation [SF]
24. Ummm … [?]
25. That's not how you spell ideation [SW]
26. Ideation [?]
27. we need to turn this product into a … [SW]
28. so it still needs to have its function but it also needs to be turned into a light shade [GS]
29. so what do we know about light shades? [EA]
30. ummm … [?]
31. design and make packaging for a light bulb that can also be used as the light shade/lamp shade for the same light bulb. [EC]
32. alright here’s our ideation so I will do something else [SF]
33. ummm … [?]
34. why … [SW]
35. why buy … [?]
36. … (there is a long pause as Subject P draws a solution on his worksheet of paper) [EC]
37. so we will go with the ummm lamp shade [EA]
38. ummm … [?]
39. To use paper as the lamp shade to shade light off the ceiling [EA]
40. incandescent lights will fit in as per the drawing and the round lightbulb will screw into it … into the side of it [SY]

T5 17:36

1. so we can … [SW]
2. At the moment there is sort of wasted light coming back up [EA]
3. so we can possibly have a diffuser that can … stop light from coming up [SY]
4. so [SW]
5. a bit of an idea which will direct light down [SY]
6. instead of ummm lost light ummm up onto the ceiling [EA]
7. that's same possible design [EA]
8. ummm … [SW]
9. there could be a fire hazard there [EA]
10. ummm … [?]
11. ummm … right [?]
12. ummm … [?]
13. Right, how does … [EC]
14. the materials … size of the materials whilst constrained by the lightbulb [EA]
15. The materials from the box [EA]
16. Ok [?]
17. So [?]
18. Materials [EC]
19. Sorry ummm … [SW]
20. Solution 1 [EC]
21. Ummm … [?]
22. Phew … [?]
23. Solution, solution 1 [EC]
24. to prevent … [EA]
25. to prevent … [EA]
26. to prevent fire hazard inside of the lampshade [GS]
27. ummm … [?]
28. … (there is a long pause as Subject P writes down a solution on his worksheet of paper) [EC]
29. this will also prevent light [SW]
30. with the reflection of light we may be able to move to a lower wattage light [SY]
31. this will also reflect light [EA]
32. ummm … [?]
33. the reflection [SW]
34. so what does that give us? [EC]
35. having the foil inside doesn't quite still make it sustainable and recyclable [EA]
36. so you won't be able to recycle the product as cleanly as you would if you only had cardboard [EA]
37. however there might be an offset with the reflection of light ummm coming from the supplied shade [SY]
38. we will be able to have lower wattage and that will have an offset of … possible sustainability [SY]
39. ummm … [SW]

T6 22:10

1. Oh, foil is recyclable too isn't it? [EA]
2. So therefore, phew, look at that solved that one, recycled [EA]
3. right, solution one [SW]
4. functional fixedness don't stay on the one solution [SF]
5. ummm another idea [SW]
6. another idea [EC]
7. (describing a new lampshade whilst drawing it on his worksheet) when there is a lampshade they go that way [SY]
8. comes down that way [SY]
9. while I suppose you could have … [SW]
10. for more of a directional … light [EA]
11. ummm … [?]
12. so that would give you a wide beam [EA]
13. solution 2 [SW]
14. solution 2 is have more of a spotlight or down-light [GS]
15. using, using incandescent light [EA]
16. ummm [SW]
17. using the box, the box idea [EA]
18. ummm [SW]
19. this will function in kind of … [EA]
20. ok [SW]
21. ummm … down light [EA]
22. this will function similar to solution 1 using the same materials [TR]
23. ok [SW]
24. (sigh) … [?]
25. Okay the first side is going to be [EA]
26. it is going to be about [EA]
27. it is going to be [EA]
28. it is going to be [EA]
29. (as per the video Subject P is now drawing up his template so that he can make his design) [SY]
30. 55, 55, 55 x 90 then [SY]
31. so that's 220 [SY]

**T7 26:04**

1. ummm 220 by 90 [SY]
2. so that's the lightbulb we want to be able to protect the ends [SY]
3. so that's going to be … [SY]
4. what did I say, 220 [SY]
5. yeah, close enough [EV]
6. (as per the video there is a long pause as Subject P is drawing up his template so that he can make his design) [SY]
7. (research assistant asks ‘what are you thinking now?’)
8. Ahhh, this is going to be a semi-prototype for a spotlight [SY]
9. okay we need to fold it up and we will see how we can develop the actual packaging into a … [SY]
10. Ah, crap [EV]
11. I needed to do it bigger [SY]
12. it needed to have a tab [SY]
13. a gluing tab … on the end of it [SY]
14. and there is my gluing tab [SY]
15. so we are just going to fold this up … and hopefully I got all of them [SY]
16. we will see or not … [EV]
17. which will … when folded up into [SW]
18. this is where I needed that gluing tab … that little tag [SY]
19. so I will just create a tag here not thinking about it [SY]
20. ummm … [?]
21. Sharp scissors [SW]
22. I am just going to get my research assistant to find the end of that [SF]
23. (as per the video there is a 2 minute pause as Subject P is making his design) [SY]
24. alright, I made it to big but that's okay [EV]
25. so that's our Star product so we have … [MO]
26. That will go there and that will go there [SY]
27. having card will be … a lot stronger than what the paper will be [SY]

T8 30:38

1. that's supposed to fit in there like that prevent the light from falling through … [SY]
2. and … [?]
3. Does …, does, does … [SW]
4. Ummm … [?] 
5. … (long pause) [?]
6. I will just make some cuts in there so they are the same [SY]
7. Ummm … [SW]
8. If so this is really … an existing product that we already have [RE]
9. that fits in there [SY]
10. that goes in there [SY]
11. that goes in there supposedly and stops it from … from falling out [SY]
12. ummm [SW]
13. my idea … now needs to … when it's in the light fitting … foldout … open up [SY]
14. ummm … [SW]
15. to as … so as it won't be into to a close contact with the cardboard when it gets hot [SY]
16. but having it lined with Alfoil … Alfoil … ummm … will help insulate the cardboard [SY]
17. ummm [SW]
18. without doing some product testing and analysis [SF]
19. I think ummm I think it will probably work [EV]
20. Ummm [SW]
21. currently these two designs don't have … [EA]
22. ummm [?]
23. or this one does [EA]
24. has the ability for the lights to be reflected down [EA]
25. but the spotlight doesn't have [SW]
26. the second solution for a spotlight doesn't have the solution for it to force the light to be directed down [EA]
27. ummm [?]
28. so [SW]
29. when that is screwed into the light fitting [EA]
30. we need to be able to do this [SW]
31. we need to stop the light … this fitting from falling out [SY]
32. ummm [?]
33. ummm [?]
34. we think this box [SW]

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35. we could have a … top on the box with a whole with in it [SY] 
36. so [SW] 
37. the … screw [EA] 
38. ok the screw could go up there and could be shown through however if 
   Alfoil comes into contact with we are going to be having an 
   unsustainable solution [SY] 
39. ummm … [?] 
40. ummm … [?] 
41. ok [?] 
42. ummm … [?] 
43. what else can we do [SW] 
44. how else can we do this [SF] 
45. ummm [?] 
46. for a lampshade [EC] 
47. ummm … [SW] 
48. Modifications would be needed to actually hold the lampshade unit 
   [SF] 

T9 35:12

1. Ummm … [SW] 
2. What would be … [EA] 
3. the connector up here [EA] 
4. Ummm [SW] 
5. It could have [EA] 
6. Ummm [SW] 
7. I don't know how to draw it [EV] 
8. Ummm [SW] 
9. the base that the light screws into [SY] 
10. the same [SW] 
11. ummm [?] 
12. ummm [?] 
13. can come down on to the screw part [SY] 
14. terminal in there [SY] 
15. screw part goes in [SY] 

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16. ummm … [SW]
17. From here have … a… prong system [SY]
18. Just like coat hangers that can squeeze together to hold a packet in place [SY]
19. if that makes sense [EV]
20. ummm … [SW]
21. That will … prevent Alfoil coming into contact with the light or with the fitting which will get around that problem [SY]
22. Ummm … [SW]
23. That's from the manufacturers point of view while it could be adaptable you could buy it ummm for a light fitting [EA]
24. this is diverging from the actual problem [SW]
25. but to use this as a product [EA]
26. ummm [SW]
27. that base … could come as a package deal but then you are going to need an electrician to rewire it [EA]
28. ummm [SW]
29. so it needs to be a fit-on solution [SY]
30. ummm [SW]
31. you would only want to do it once [EA]
32. I was thinking you could buy … you could buy the first kit and that could be somehow in the packet but that's getting further away from … the circle [SY]
33. ummm … [SW]
34. I wonder if all those fittings that these screw into are the same … the same size [EC]
35. and then you could possibly in the top of the box have that as a push on [SY]
36. as a push on system [SF]
37. ummm … [?] 
38. ummm … [?] 
39. the light [SW]
40. but the development of this one … [EA]
41. I would probably be inclined to use a round style tube [SY]
42. Ummm … [?]
43. Let's see [SW]
44. … (a long pause while Subject P assembles his lampshade design)
45. using pi’s let's find its widest point [SF]
46. Ummm … [SW]
47. eighteen mm [EA]

T10 39:06
1. Ummm … [SW]
2. What does your ticktock say? [?] 
3. (Research Assistant answers ‘15 min to go’)
4. that's 15 to go? [?]
5. Ummm …[?]
6. … (a long pause while Subject P continues to assemble his lampshade design)
7. so this is going to be hopefully my … Light package for … [EA]
8. That needs to be a bit bigger [EV]
9. Umm [SW]
10. finishing off a round idea where that's like that and that's like that [SY]
11. … and from memory of those light systems … [RE]
12. the actual … paper … is [EA]
13. ahhh broke the bulb [SW]
14. that has just crumpled in on its self [EA]
15. like so [EA]
16. and like so [EA]
17. and that stops the light from coming out [SY]
18. so you unwrap the light … and get it out [SY]
19. oh no the lamps to tight [EV]
20. Ummm [SW]
21. now that shape needs to be evolved into … [SY]
22. the development of that will be … something like that [SY]
23. and currently my development of the same thing will be like that [SY]
24. Ummm … [SW]
25. Perforated … perforated edge in there which can be torn away and … separated there and be torn away [SY]
26. have a tab … interlocking tab system somehow there and again there [SY]
27. ummm … [?]
28. And possibly … interlocking tab system inside [SY]
29. a slit in there [SW]
30. and so … [SW]
31. The same product will have cardboard recycled [SF]
32. Ummm [?]
33. Recycled [EA]
34. Ummm [SW]
35. Packaging will be [EA]
36. Ummm [?]

39:06 END of TAPE
1. (Subject P is reading the ASIT notes) [EC]
2. Multiplication [EC]
3. Object Removal [EC]
4. I am just thinking [SW]
5. all right, what we are going to do is … list here what the actual problem is [SF]
6. ummm … [?]
7. which is what it says here [EC]
8. … (long pause) [?]
9. See the problem statement is we don't have enough money [EC]
10. so … [SW]
11. we don't have the means to move all the books [EC]
12. so [SW]
13. ummm [?]
14. Brisbane library needs to move all the books from the old town library to the new one [GS]
15. we only … we have is a budget of $50,000 to remove the books and all the estimates from the removers far exceed the budget [EC]
16. list all of the conditions [SW]
17. include all the conditions of the closed world [EC]
18. phew [?]
19. closed world conditions require that no new types of objects be included into solving of the solution [EC]
20. the qualitative change condition examines changing the relationship between the undesired effect and the worsening factors [EC]
21. we don't have enough money to move our books [EC]
22. list all the problems in the problem world [EC]
23. removers, books [EA]
24. needs to have … [SW]
25. Needs to move all the books in the old library to the new library [GS]
26. … (long pause) [?]
27. it doesn't state how … long we have to remove it [EC]
28. so [SW]
29. list all the objects in the solution world [EC]
30. … (long pause) [SW]
31. Define the problem world [EC]
32. using ASIT define the problem [EC]
33. … (sigh) [SW]
34. closed world [EC]
35. determine the wanted action [EC]
36. we need to move the books [GS]
37. … (long pause) [?]
38. move books[EA]
39. ummm ... It [?]
40. … (long pause) [?]
41. Ummm … [?]

T2 07:05

1. (Research Assistant asks ‘what are you thinking?) I am thinking if possibly to help move the books we could use people who are taking the books out from the library when they are hiring the books on loan that the books go back to …ummm ... the new library [SY]
2. Possibly [SW]
3. ummm ... [?]
4. also thinking possibly [SW]
5. ummm ... [?]
6. … (long pause) [?]
7. So [?]
8. ummm ... [?]
9. … (long pause) [?]
10. Ummm … [?]
11. move the books [SW]
12. that means [EC]
13. so the thing is how do we do it [EC]
14. we can't … [SW]
15. Closed world environment [EC]
16. close world environment means no new types of objects can be
   introduced into the solution [SW]
17. … (long pause) [?]
18. nothing new can be created [EC]
19. see the solution statement [EC]
20. to move the books [GS]
21. which is what I have done [EV]
22. there is nothing creative about our solution statement [EC]
23. okay [EV]
24. phew [?]
25. so [SW]
26. list the problem [EC]
27. list the environment [EC]
28. determine the wanted action [EC]
29. multiplication [EC]
30. the cost [EC]
31. derive the unwanted action [EC]
32. we still need the books to be moved [GS]
33. … (long pause) [?]
34. the define the wanted action [EC]
35. definition of the action [EC]
36. less creative [EV]
37. I'm using this one here [SF]
38. Ummm … [SW]
39. Multiplication [EC]
40. Ummm what was that …? [SW]
41. The books will prevent ummm … the unwanted action [EA]
42. determine the wanted action from the definition [EC]
43. the books will help move [EA]
44. the books will help move the books to the new library [EA]
45. new library … will help move … the books from the old one [EA]
46. The books will move the books to the new library [EA]
47. list all the problem objects [EC]
48. due to the change [SW]
49. problem world [EC]
50. problem world [EC]
51. the problem world is where the books are [EC]
52. the wanted action [EC]
53. sorry Steve [SW]
54. sorry mate [?]
55. ummm … [SW]
56. You can't … you can't seem to multiply [EC]
57. this thing just seems to want to … to go through the whole thing again [SW]
58. multiplication means [EC]
59. ummm … [?]
19. … (long pause) [?]
20. I am just trying [SW]
21. once again how do you get those books ummm … to there … using the multiplication [EC]
22. using multiplication [EC]
23. so I was going to do one sheet per … ASIT design [SY]
24. ummm … [SW]
25. and I’m stalled [MO]
26. so just sort of [?]
27. ummm … [?]
28. Sorry [SW]
29. by adding … by adding a another condition into it will solve this problem [SY]
30. ummm … [SW]
31. So once again using the ummm … [EC]
32. So [SW]
33. Ummm … [?]
34. The possible solution [EC]
35. I'm guessing once again [MO]
36. Ummm … [?]
37. … (long pause) [?]
38. Instead of using Removalists [SW]
39. … (long pause) [?]
40. Ummm … [?]

**T4 14:03**

1. To, to move the books ummm … use ummm … borrowers to move the books … books to … the new site [SY]
2. which [SW]
3. ummm … [?]
4. And by doing that [SW]
5. Ummm … [?]
6. By doing … this solution you are going to have … [EA]
7. Ummm … [SW]
8. over a period of time … [EA]
9. Ummm … [SW]
10. Solution move the books [GS]
11. to move the books [EA]
12. to move the books [EA]
13. use borrowers to return books ummm … to the new site [SY]
14. ummm … [?]
15. Volunteers to ummm … [EA]
16. Volunteers [EA]
17. how do you spell it? [SW]
18. This is why I am not doing English Steve [?]
19. Ummm … [SW]
20. That's wrong, a little help [EV]
21. Helpers [EA]
22. free helpers to shift … [SY]
23. Free helpers to shift books [SY]
24. … (long pause) [?]

T5 17:52

1. by having [SW]
2. by having these solutions with… [EC]
3. with the introduction … [SW]
4. I’m, I’m pretty sure it is multiplication [SY]
5. is the ummm … [SW]
6. … (long pause) [?]
7. the thing that I am looking forward to … [SW]
8. by having these … solutions ummm … put into it you are going to reduce the amount of books that are in the library and therefore … [SY]
9. The removals company can … [SW]
10. and the removals can come in with the others [SY]
11. ummm … [SW]
12. I have listed the solutions [EC]
13. the solutions [EC]
14. … (long pause) (at this stage subject P is referring back to his ASIT notes) [EC]
15. remove the books, the job [EA]
16. ummm … [?]
17. … sigh [?]
18. ummm … [?]
19. ummm … [?]
20. … sigh [?]
21. define the objects [EC]
22. going to and fro … [SW]
23. just stuck on one thing [MO]
24. just focusing on that [MO]
25. I don't think I can divide the job if I want to [EA]
26. I am wondering if I can use the division tool [MO]
27. if there is a way to put it into to help solve the solution [EA]
28. ummm … [?]
29. If … [SW]
30. … sigh [?]
31. I am just reading the query question and seeing how I can apply it back to our problem [EC]
32. Ummm … [SW]
33. The problem objects [EC]
34. the books [EA]
35. ummm … [?]
36. The distance between the two places [EA]
37. Ummm … [?]

T6 21:01

1. The environmental objects [EC]
2. So [SW]
3. the books [EA]
4. ummm … [SW]
5. This is probably sought of moving further away from ummm … the information we've got … we’ve got but [MO]
6. Ummm … [SW]
7. but, the budget of $50,000 to move all the books [EA]
8. ummm … [SW]
9. It could quite possibly be instead of getting volunteers ummm … to do it [EA]
10. Ummm … [?]
11. Ummm … [?]
12. This is [SW]
13. This is from what I can remember ummm … from the class is that you keep spiralling outwards and the further you get away from the solution [RE]
14. Ummm … [?]
15. You’re … [SW]
16. The problem becomes more complex [EC]
17. Ummm … [SW]
18. And … so try to keep it within the box is the … the thing [SF]
19. I think our constraints are … here … [EC]
20. Ummm … [SW]
21. What I'm thinking [EA]
22. Ummm … [?]
23. Is maybe possibly even [SW]
24. I don't know where it is going to fall into what category [MO]
25. ummm … [SW]
26. But instead of having [EA]
27. Ummm … [SW]
28. The price to do that … a price on … a price on … say using volunteers [EA]
29. ummm … [?]
30. Instead of ummm … them doing it and then the volunteers shifting it which I think would be an environmental [SY]
31. ummm [SW]
32. object [EC]
33. packing of the books [EA]
34. ummm … [?]
35. So going back from the ummm other side of this ummm back here [SW]
36. ummm … [?]
37. ummm … [?]
38. … (long pause) (at this stage subject P is referring back to his ASIT notes) [EC]
39. staff, helpers, books not Removalist [EA]
40. therefore the Removalist [EA]
41. the Removalists need to transport [EA]
42. ummm … [SW]
43. That’s ummm … at the other end when they unpack it ummm … [EA]
44. the Removalists won't be unpacking it they will be the volunteers and the staff will be unpacking it [SY]
45. Ummm [SW]
46. So they … ummm … will be putting it into all the categories [SY]
47. I don't know … where it's got to go on the racks [SY]
48. So [SW]
49. why can't [EA]

T7 24:50

1. but what we do not know is exactly what the simple cost is in there for packing or if it was just the transporting to move all the books from the old library to the new library [EC]
2. … (long pause) [SW]
3. determine the wanted action (at this stage subject P is referring back to his ASIT notes) [EC]
4. definition [SW]
5. ummm [?]
6. ummm [?]
7. a factor … thinking … thinking outside the square here [SF]
8. a factor that is not included [SF]
9. hence the timeframe they have to move it [EA]
10. ummm … [SW]
11. So … so the timeframe here ummm can also have [EA]
12. If [SW]
13. what am I trying to say [SF]
14. ummm …
15. If they have got six months to move you can have [SF]
16. this is getting outside [SW]
17. to me it's getting outside or further away from the problem because
   ideally wanted to be done in a short space of time [SF]
18. ummm … [?]
19. ummm … [?]
20. ummm … [?]
21. Yeah I don't know [EV]
22. that's the best of got Steve [EV]
23. object removal [SW]
24. let's investigate that [EA]
25. ummm … [?]
26. ummm … [?]
27. (At this stage subject P is reading from his ASIT notes) [EC]
28. Ummm [SW]
29. object removal in terms of … in terms of the books [EA]
30. ummm [?]
31. I mean with … with object removal [EA]
32. Ummm [?]
33. If ummm … we know we have got to move the books ummm from one
   site to the … to the next [EC]
34. Ummm [SW]
35. and I don't know if that object removal [RE]
36. ummm [SW]
37. comes back here to the multiplication [EC]

T8 28:39

1. I am toying with multiplying the books [SF]
2. to find the people who are involved in ummm the scenario to move the
   books [SY]
3. this one here [SW]
4. I think I could also assign object removal by saying if you remove books from there to go to the new, the new library [SY]

5. I am wondering [SW]

6. I am wondering if that's [EC]

7. Ummm [?]

8. can be assigned object removal [EC]

9. but it's doing the same thing [EC]

10. ummm [?]

11. object removal [SW]

12. multiplication [EC]

13. ummm [SW]

14. object removal [EC]

15. ummm

16. the problem objects [EC]

17. the problem objects [EC]

18. maybe remove the object [EA]

19. ummm [?]

20. sigh [SW]

21. problem objects [EC]

22. the books problem objects [EA]

23. ummm [?]

24. ummm [?]

25. ummm [?]

26. by removing books [EA]

27. by removing books [EA]

28. by removing books [EA]

29. by removing books [EA]

30. the library [SW]

31. by removing books to the library could [SF]

32. ummm [?]

33. by removing books to the library could [EA]

34. ummm … [?]

35. by removing books to ummm … the new library [EA]

36. ok how am I going to do it? [SW]
37. Ummm … [?]
38. Once again use ummm … the borrowers to take [EA]
39. the borrowers of the books to remove … to remove the books [EA]
40. ummm … [?]
41. … (long pause) [?]
42. Ummm … [?]

T9 31:48

1. Division, Multiplication [EC]
2. Division, division, division [EC]
3. The division tool might be ummm …[EC]
4. Ummm … [SW]
5. No Changed relationship [EC]
6. Ummm … [?]
7. (Subject P is reading from the ASIT material) [EC]
8. Name an object and make a list of its attributes and change these into a
   list of new functions [EC]
9. ummm … [?]
10. Laughing [?]
11. Ummm … [?]
12. Right, once again … [SW]
14. Ummm … [?]
15. Books [EA]
16. Ummm … [?]
17. … (long pause) [?]
18. Ummm … [?]
19. What’s the cost? [EC]
20. (Subject P is reading from the ASIT material) [EC]
21. Division [EC]
22. Division [EC]
23. (Research Assistant asks ‘what are you thinking now?’) Ahhh … just
    how to write what I am trying to think [SF]
24. Ummm … [SW]
25. Basically I think it can be linked back to this one [RE]
26. this one is the division of the shift [EC]
27. if instead of shifting the whole library [EA]
28. ummm … [SW]
29. By the volunteers [EA]
30. by the removals company [EA]
31. ummm … [SW]
32. Divide your most ummm … most popular books that get used and shift them over to the new town library [SY]
33. ummm … [SW]
34. But once again does that fit into the realms of fixing the problem [MO]
35. Ummm … [SW]
36. Books [EA]
37. Ummm … [?]
38. Books [EA]
39. ummm … [?]
40. … (long pause) [?]
41. most referenced [EA]
42. referenced books [EA]
43. choose categories [EA]
44. books [EA]
45. choose categories [EA]
46. ummm … [?]
47. Spelling [?]
48. Ummm … [?]
49. Ummm … [?]
50. Most read books moved by Removalists [SY]
51. Removalists [EA]
52. Ummm … [SW]
53. By doing it … by doing it that way it's going to have ummm … all the resources in one place ummm … versus ummm … whatever is taken by volunteers or … or however it gets done [SY]
1. Ummm … [?]
2. With [SW]
3. Ummm … [?]
4. The problem is going to be is if I [SW]
5. with doing this one is if I go to a new library and I want a book that is at the old library … I am going to be caught out [EV]
6. Ummm … [SW]
7. That's the same here with uni … if there is no books here you can get one sent up … sent over through Nathan or whatever [EA]
8. ummm … [SW]
9. So that will also be another way of ummm … that would be another way of transporting books if someone is already making a trip ummm … across to deliver a category a section of books they can take that much resources with them [TR]
10. Ummm … [?]
11. Ummm … [?]
12. Ummm … [?]
13. What else [SW]
14. Ummm … [?]
15. Can't do it [EV]
16. … (long pause) [?]
17. can't do it [EV]
18. no can't do it [EV]
19. Ummm … [?]
20. Ummm …[?]
21. (Research Assistant asks ‘what are you thinking now?’) Now I’m try to work out where that … where that fits 'cause your books categories that are ummm … that are most referenced are removed by the Removalists [EA]
22. And [?]
23. Ummm … [?]
24. Ummm … [?]
25. I don’t think that's [SW]
26. Ummm … [?]
27. Ummm … [?]
28. Ah well here we go … the books categories that are most referenced are removed by the Removalists [TR]
29. Ummm … [SW]
30. The overall arching question is uummm … can all uummm … [EA]
31. No actually [SW]
32. do all books need to be kept [EC]
33. can some books be given away or archived [EA]
34. Ummm … [?]

35:37 END of TAPE
APPENDIX 4

Sustainability and Packaging Design Brief

The Design Brief

Problem Context
Most packaging for the goods we buy is discarded after we have un-wrapped the products and ends up wasted in landfill. In an effort to save our valuable resources and reduce waste packaging must become re-usable.

Design Challenge
Your challenge is to design and make packaging for a lightbulb that can also be used as the light shade/lamp shade for the same light bulb.

Inclusion

- You are given a selection of paper and equipment such as lightbulb, scissors, glue, staplers etc. to complete the challenge.
- You are to work on the design challenge individually (this is not a team challenge).
- At the end of the design challenge students are asked to present their solution and discuss the designing and making issues they encountered and how they were solved.
- Students are encouraged to ask ‘teacher’ questions of the student presenting to draw out more information about their design solution.
- You have 1 hour to complete the design challenge.
APPENDIX 5

The Brisbane Library Design Brief

Design Brief

The Brisbane Library needs to move all of the books from the old town library to the new town library. However, the library only has a budget of $50,000 to move the books and all of the estimates from the Removalist companies far exceed the library’s budget. Your design challenge is to find a way of moving all of the libraries books for $50,000.

Two ASIT conditions exist for creative solutions:

- Closed World condition (suggest illustration)
- Qualitative Change condition (ditto)

The Closed World condition requires that NO NEW TYPES of objects may be introduced into the solution

Qualitative Change condition examines changing the RELATIONSHIP between an undesired effect and the cause of that effect (Worsening Factor)

Simple Problem Statement:

“We don’t have enough money to move all our books”

Note: There is nothing creative about our problem statement

Simple Solution Statement:

“To move the books”

Note: There is nothing creative about our solution statement

List all objects in the Problem World

Problem Objects -

_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________

Environment Objects

_____________________________________________________________________

_____________________________________________________________________
List all objects in the Solution World

Problem Objects -

Environment Objects

Note: The Closed World requires that the Problem World and Solution World objects are the same types

Sample List of objects for Library case study

Problem Objects:

• Books
• Budget
• Movers
• Library
• Distance to New Library

Environment Objects:

• Book Borrowers
• Library Staff
• Other people
• Streets
• Other vehicles on the streets

The whole idea of ASIT is that the method forces us to check all the solution directions we would probably not consider without the method.
Which ASIT tool will you use to solve this ASIT problem?

- The Unification Tool Unless you have it elsewhere you need a brief description of each of these
- The Multiplication Tool
- The Division Tool
- The Breaking Symmetry Tool
- The Object Removal Tool

You have 1 hour to complete the design challenge.
APPENDIX 6

Sample Manual Arts Job sheet (1)
APPENDIX 7

Sample Manual Arts Job Sheet (2)
REFERENCES


