DESIGN AND PROBLEM – FINDING IN HIGH SCHOOLS: A
STUDY OF STUDENTS AND THEIR TEACHER IN ONE
QUEENSLAND SCHOOL

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A thesis submitted in fulfilment of the requirements for the Degree of Master of Philosophy

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DECLARATION

The work presented in this thesis has not previously been submitted, either whole or in part for a degree at this or any other university. To the best of my knowledge and belief, the thesis is original, containing no material previously published or written by another person except where due reference is made in the text itself.

Peter Andrew Tracy
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ABSTRACT

The study challenges current literature, which views the notion of problem-finding as the initial identification of a problem to be solved. The concept of problem-finding in this study is that problem-finding continues throughout the problem-solving process and is not distinct from it. This thesis aims to develop a better understanding of problem-finding by examining high school students using problem-finding to solve industrial design problems. The study seeks to find out what types of problem-finding exist and what roles they play in solving design problems.

To explore problem-finding, this study uses a Think Aloud methodology to examine the thinking of three high school industrial design students and one high school industrial design teacher solving an authentic industrial design problem. Protocol data was gathered from the subjects and then transcribed, segmented and analysed in three ways, each of which became progressively more specific: Firstly, a macroscopic examination which identified problem-finding episodes occurring throughout the design process; secondly, a microscopic examination which identified four categories of problem-finding; and lastly, a microscopic examination which looked at the role played by the different problem-finding categories in solving design problems.

The findings of this study are fourfold. Firstly, problem-finding was found to be used throughout the entire design process. Secondly, there were four categories of problem-finding. Thirdly, each category played an important role predominantly through interaction with other categories. Lastly, the more experienced a person was, the more able they were to use problem-finding effectively to solve design problems.
Many current practices use trial and error methods to solve design problems. The importance of this study is that through a better understanding of problem-finding, designers may be able to use metacognitive strategies more efficiently in the process. Similarly, in educational practice, high school design students may be able to learn to think about the methods they use to solve design problems, and this may result in more creative designs.
# Table of Contents

**CHAPTER 1: INTRODUCTION** ................................................................. 1
- Introduction .................................................................................................................. 1
- Structure of the Thesis .................................................................................................. 4

**CHAPTER 2: LITERATURE REVIEW** ....................................................... 6
- Introduction ................................................................................................................... 6
- Introduction to Key Research Questions ........................................................................ 6
- Significance of the Research Questions ....................................................................... 7
- Problem-Finding .......................................................................................................... 9
  - Definition of problem-finding .................................................................................... 9
  - Cognitive functions in problem-finding ..................................................................... 10
  - Problem-finding and creativity .................................................................................. 14
  - Categories of problem-finding ................................................................................. 15
- What is Design? .......................................................................................................... 18
- Design Thinking ......................................................................................................... 20
- Design Methods .......................................................................................................... 23
- The School Level ......................................................................................................... 26
- Cognitive Processes for Designing ............................................................................. 27
- Originality and Creativity ............................................................................................ 30
  - Kinds of creativity .................................................................................................... 30
  - Promoting originality ............................................................................................... 31
  - Teaching originality ................................................................................................. 32
- Theoretical Models of Design Problems ....................................................................... 34
- Conclusion .................................................................................................................. 38

**CHAPTER 3: METHODOLOGY** ................................................................. 41
- Introduction .................................................................................................................. 41
- Design Research Methodologies .................................................................................. 43
  - Structured interviews ............................................................................................... 43
  - Observations ............................................................................................................. 44
  - Verbal Protocol Studies ............................................................................................. 44
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retrospection</td>
<td>44</td>
</tr>
<tr>
<td>Introspection</td>
<td>46</td>
</tr>
<tr>
<td>Think Aloud</td>
<td>47</td>
</tr>
<tr>
<td>IMPLEMENTATION OF THINK ALOUD METHOD FOR DATA GATHERING</td>
<td>48</td>
</tr>
<tr>
<td>Selection of the design task</td>
<td>49</td>
</tr>
<tr>
<td>Participant selection</td>
<td>50</td>
</tr>
<tr>
<td>Skill Level Classification</td>
<td>53</td>
</tr>
<tr>
<td>Selection of the setting</td>
<td>57</td>
</tr>
<tr>
<td>Collection of the data</td>
<td>58</td>
</tr>
<tr>
<td>PREPARATION OF DATA FOR ANALYSIS</td>
<td>59</td>
</tr>
<tr>
<td>Segmentation of the transcripts</td>
<td>60</td>
</tr>
<tr>
<td>Coding the data</td>
<td>60</td>
</tr>
<tr>
<td>DATA ANALYSIS METHOD</td>
<td>63</td>
</tr>
<tr>
<td>Data Analysis Stage 1</td>
<td>64</td>
</tr>
<tr>
<td>Data Analysis Stage 2</td>
<td>65</td>
</tr>
<tr>
<td>STRENGTHS AND LIMITATIONS OF THE STUDY</td>
<td>66</td>
</tr>
<tr>
<td>Internal Reliability</td>
<td>67</td>
</tr>
<tr>
<td>Inter-coder reliability</td>
<td>67</td>
</tr>
<tr>
<td>Macro level inter-coder reliability</td>
<td>67</td>
</tr>
<tr>
<td>Micro level inter-coder reliability</td>
<td>68</td>
</tr>
<tr>
<td>External Reliability</td>
<td>69</td>
</tr>
<tr>
<td>Internal Validity</td>
<td>69</td>
</tr>
<tr>
<td>External Validity</td>
<td>71</td>
</tr>
<tr>
<td>People</td>
<td>72</td>
</tr>
<tr>
<td>Places and Time</td>
<td>73</td>
</tr>
<tr>
<td>Setting</td>
<td>73</td>
</tr>
<tr>
<td>CONCLUSION</td>
<td>77</td>
</tr>
<tr>
<td>CHAPTER 4: RESULTS AND ANALYSIS</td>
<td>78</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>78</td>
</tr>
<tr>
<td>OCCURRENCE OF PROBLEM-FINDING IN PROBLEM-SOLVING</td>
<td>78</td>
</tr>
<tr>
<td>Comparison of frequency of problem-finding between subjects</td>
<td>79</td>
</tr>
<tr>
<td>Results</td>
<td>79</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Analysis</td>
<td>80</td>
</tr>
<tr>
<td>Comparison of problem-finding over time divided into quartiles</td>
<td>84</td>
</tr>
<tr>
<td>Results for Subject S1</td>
<td>85</td>
</tr>
<tr>
<td>Analysis for Subject S1</td>
<td>85</td>
</tr>
<tr>
<td>Results for Subject S2</td>
<td>86</td>
</tr>
<tr>
<td>Analysis for Subject S2</td>
<td>86</td>
</tr>
<tr>
<td>Results for Subject S3</td>
<td>87</td>
</tr>
<tr>
<td>Analysis for Subject S3</td>
<td>87</td>
</tr>
<tr>
<td>Results for Subject S4</td>
<td>88</td>
</tr>
<tr>
<td>Analysis for Subject S4</td>
<td>88</td>
</tr>
<tr>
<td>Comparisons across Subjects</td>
<td>89</td>
</tr>
<tr>
<td>Analysis</td>
<td>89</td>
</tr>
<tr>
<td>CATEGORIES OF PROBLEM-FINDING AND THEIR ROLES IN DESIGNING</td>
<td>92</td>
</tr>
<tr>
<td>Holistic Examination of problem-finding categories</td>
<td>94</td>
</tr>
<tr>
<td>Results for Clarification</td>
<td>95</td>
</tr>
<tr>
<td>Analysis for Clarification</td>
<td>95</td>
</tr>
<tr>
<td>Results of Elimination</td>
<td>96</td>
</tr>
<tr>
<td>Analysis of Elimination</td>
<td>96</td>
</tr>
<tr>
<td>Results of Exploring Ideas</td>
<td>97</td>
</tr>
<tr>
<td>Analysis for Exploring Ideas</td>
<td>97</td>
</tr>
<tr>
<td>Results for Lack of Knowledge</td>
<td>98</td>
</tr>
<tr>
<td>Analysis of Lack of Knowledge</td>
<td>98</td>
</tr>
<tr>
<td>Combination of problem-finding categories across all subjects</td>
<td>99</td>
</tr>
<tr>
<td>Individual examination of the interaction of problem-finding categories</td>
<td>100</td>
</tr>
<tr>
<td>Results for Subject 1</td>
<td>100</td>
</tr>
<tr>
<td>Analysis for Subject 1</td>
<td>101</td>
</tr>
<tr>
<td>Results for Subject 2</td>
<td>102</td>
</tr>
<tr>
<td>Analysis for Subject 2</td>
<td>103</td>
</tr>
<tr>
<td>Results for Subject 3</td>
<td>104</td>
</tr>
<tr>
<td>Analysis for Subject 3</td>
<td>105</td>
</tr>
<tr>
<td>Results for Subject 4</td>
<td>106</td>
</tr>
<tr>
<td>Analysis of Subject 4</td>
<td>107</td>
</tr>
<tr>
<td>Results of the sequencing of patterns between categories</td>
<td>109</td>
</tr>
<tr>
<td>Analysis of the sequencing of patterns between categories</td>
<td>110</td>
</tr>
</tbody>
</table>
CHAPTER 5: DISCUSSION AND CONCLUSIONS ................................................................. 122

INTRODUCTION .............................................................................................................. 122

THE FINDINGS TO THE RESEARCH QUESTIONS ....................................................... 123

Discussion on Research Question 1 ........................................................................... 123

Discussion on Research Question 2 ........................................................................... 125

CONTRIBUTIONS OF THE STUDY ............................................................................ 129

PRACTICAL APPLICATIONS OF THE STUDY ............................................................... 131

FURTHER RESEARCH .................................................................................................. 132

REFERENCES .................................................................................................................. 134

List of Figures

Figure 2.1: Correlation model between problem situations and cognitive functions. 11

Figure 2.2: Comparison of the levels of problem-finding and problem-solving ......... 13

Figure 2.3: Theoretical model of problem-finding (Hoover, 1994) ............................ 35
Figure 2.4: Problem-solving model (Middleton, 1998) .................................................. 36
Figure 2.5: Geneplore model (Finke, Ward and Smith, 1992) ........................................ 38
Figure 3.1: Sample of macro coding ............................................................................. 61
Figure 3.2: Frequency of problem-finding by time quartile for subject No.3 ............. 64
Figure 3.3: Comparison of Clarification by time in quartiles ...................................... 66
Figure 4.1: Graph of the total number of problem-finding episodes ......................... 79
Figure 4.2: Graph of problem-finding by subject S1 .................................................... 85
Figure 4.3: Graph of problem-finding by subject S2 .................................................... 86
Figure 4.4: Graph of problem-finding by subject S3 .................................................... 87
Figure 4.5: Graph of problem-finding by subject S4 .................................................... 88
Figure 4.6: Graph of comparisons between all subjects .............................................. 89
Figure 4.7: Graph of Clarification .............................................................................. 95
Figure 4.8: Graph of Elimination .............................................................................. 96
Figure 4.9: Graph of Exploring Ideas ...................................................................... 97
Figure 4.10: Graph of Lack of Knowledge ............................................................... 98
Figure 4.11: Graph of all problem-finding categories ............................................... 99

List of Tables

Table 3.1: Five Stages of Skill Acquisition (Dreyfus & Dreyfus, 1986) ...................... 54
Table 3.2: Profile of subjects studied ......................................................................... 56
Table 3.3: Sample of micro coding ......................................................................... 63
Table 4.1: Coding table for subject S1 ................................................................. 101
Table 4.2: Coding table for subject S2 ................................................................. 102
Table 4.3: Coding table for subject S3 ................................................................. 105
Table 4.4: Coding table for subject S4 ................................................................. 107
Table 4.5: Correlation of patterns of sequencing between categories ................. 109

Table of Contents
Chapter 1: Introduction

Introduction

This thesis investigates how high school students go about designing in a practical workshop setting. The subjects for this study were enrolled in design-based study areas, which have been developed by the Queensland Studies Authority. This thesis is concerned with how students move from an initial concept to a final design. The thesis investigates this by analysing the types of problems that students may encounter when solving a design problem.

Problem-finding came to the forefront of creative research in 1976 when Getzels and Csikszentmihalyi concluded, from a twelve year study, that problem-finding may be a predictor of creativity. Little research has been undertaken on the topic in the intervening years. A search of the more recent literature found only a small number of references (e.g. Dillon 1982; Runco & Nemiro 1994; Runco 1994; Jay & Perkins 1997; Reiter-Palmon et al 1998) to problem-finding. The definition of problem-finding used in this study, however, does not concur with these previous studies’ interpretations of what constitutes problem-finding. This was because they viewed problem-finding as the initial identification of a problem before the problem can be solved. This study adopts the stance of researchers such as Michael (1997) and Getzels and Csikszentmihalyi (1976) who conclude that problem-finding was more than the definition given above and that problem-finding may continue throughout the problem-solving process. Hence this study should make a contribution to knowledge about the nature of problem-finding and its role in designing, and thus contribute to our understanding of designing and its enhancement.
Solving design problems is an every day occurrence in most Queensland high schools. The Queensland curriculum allows for students to be involved in designing through study areas such as Industrial Technology and Design, Technology Studies and Engineering Technology. All three study areas are based on industrial design and technology. The nature of these study areas is encapsulated in the following statement from the Queensland Studies Authority.

Design challenges are 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 knowledge, practices and dispositions. Students are challenged to:
• design and develop products in response to needs, wants or opportunities
• apply technology practice and use information, materials and systems
• consider appropriateness, contexts and management as they initiate, design, use, modify, and reflect on products of technology. (Queensland Studies Authority 2004a).

It is expected that the findings of this study will have implications for teaching practice. The Queensland curriculum documents in technology emphasize the need for educators to teach design; however, they give no strategies as to how this may be accomplished. One of the assumptions on which this thesis is based is that designing can be learnt and that the use of problem-finding may be a crucial part of understanding how people design.

In contrast to other studies which view problem-finding as “the formulation of a problem by an individual prior to the actions taken to solve the problem”(Kay 1991, p.253), this study assumes that problem-finding might be a continuing process throughout the solving process. Therefore, if a better understanding of how, when and why people problem-find is established it may be possible to improve the ability of people to design and hence produce better designs.
Dorner, asked if there “is one process that makes the best designs? Absolutely not!” (Dorner 1999, p.409). Dorner suggests that when ‘the design cloud begins to crystallise’ is dependent on many things such as personal and environmental conditions and the characteristics of the design problem.

Knowing more about what happens when ‘the design cloud begins to crystallise’ is central to this thesis. The cognitive processes being used to perform such steps as clarifying a problem appear to be dependent on factors such as the context of the problem and the personal experience of the problem solver (Dorner 1999, p.407). That is, it could be assumed that a more experienced person would be able to solve more difficult problems than a less experienced person because of past knowledge accumulated during previous experiences.

To find out more about how design problems are solved, the intention of this study is to investigate some of the cognitive processes occurring whilst undertaking a design task. To achieve this the study uses problem-finding as a medium to examine how people solve design problems.

Previous studies in problem-finding have been concerned with educational implications (e.g. Kay 1994; Moore 1990; Tegano et al 1989; Fredricksen 1984). These implications include:

- teachers being restricted by the curriculum in terms of their ability to encourage students to invent their own problem situations,
- textbook publishers and school administrators presenting well-defined problems in their subject matter which limits creativity, and
teachers not having the skills to help students experience the problem-finding process.

This study aims to investigate problem-finding in an educational setting. The study uses a Think Aloud protocol elicitation method to collect data for the investigation of problem-finding by three high school design students and one high school design teacher with varying levels of expertise.

This research found that problem-finding occurred throughout the designing process and that different types of problem-finding could be identified. Furthermore, each type of problem-finding appeared to be capable of taking on a number of roles. The study also found that the utilisation of problem-finding may change with the level of expertise of the designer.

The following section provides an overview of the structure of the thesis.

**Structure of the thesis**

Chapter 1 provides an introduction to the thesis, and introduces the research question. Chapter 2 gives an overview of previous research about problem-finding. The previous work of Getzels and Csikszentmihalyi (1976) focussed on identifying links between creativity and problem-finding, however this study examines how and why people engage in problem-finding in design. It draws on literature from creativity and originality studies to examine the concept of problem-finding as an important tool for problem-solving. In so doing it poses the two Key Research Questions which inform the direction of the study and the analysis of the data.
Chapter 2 also examines different design methods and the ways in which those methods vary between industrial applications and their application in design courses at high school.

Lastly, Chapter 2 looks at various models associated with designing. The study supports the need for an investigation into problem-finding by suggesting that problem-finding may be a possible tool for moving a designer from the initial identification of a problem to a solution.

Chapter 3 presents and justifies the methodology employed in the case studies. It provides an analysis of some of the different types of methodologies that have been used previously in design research. The strengths and weaknesses of each are identified and compared. Based on this analysis, the Think Aloud method is chosen as the most appropriate to conduct the research. Following this, the chapter gives a detailed description of how the Think Aloud method was applied in this study. In addition, the methods of coding and analysing the data are described and justified. Finally, the strengths and limitations of the study are presented.

Chapter 4 presents the results and analysis of the research. It does this through individually addressing the two Key Research Questions identified in chapter 2.

Chapter 5, the final chapter, summarises and draws together the findings of the research. The results of each Key Research Question are discussed in terms of how they affect designing. The contributions of the study are presented along with the practical implications and suggestions for further research.
Chapter 2: Literature Review

Introduction

This chapter examines the literature concerning problem-finding in design. The review provides the theoretical background to the empirical research, as well as identifying areas where research is lacking. The review examines the aspects of problem-finding, design and creativity as they relate to this thesis. The chapter is structured in the following way. Initially, literature on problem-finding is reviewed, then designing and its application in the classroom is explored, and finally, theoretical models associated with designing are presented.

Introduction to Key Research Questions

Researchers such as Dillon (1982) and Kay (1991) have defined problem-finding as the finding of an initial problem to be solved before the solving of that problem. Others such as (Getzels and Csikszentmihalyi 1976; Michael 1977) viewed problem-finding as a process that can continue throughout problem-solving. This study argues that problem-finding occurs throughout the solving process and not solely at the beginning. In addition to this definition, this study explores problem-finding in designing in terms of two forms which were found to occur during the problem-solving process and appeared to be different to the form of problem-finding referred to by Dillon (1982) and Kay (1991). The first of these seemed to occur when the person discovered something during the design process that would not work or was unsure how to make it work. It is when a person runs into trouble and has to change their mind or do something in a different way than they originally thought possible. The second additional form of problem-finding seemed to occur when the person created a useful situation, in terms of facilitating the design process, by raising new questions for inquiry. Therefore, because
of the data discussed in Chapter 4, the definition of problem-finding used in this dissertation includes both the detection of difficulties and the finding of new questions for scrutiny as a design unfolds. This accords with the work of Getzels (1982) who argued that the act of problem-finding is not only the finding of undesirable situations but also includes envisioning new avenues for investigation. Based on the argument that problem-finding may exist during the solving process and also on the two forms of problem-finding mentioned above, the Key Research Questions are:

1. **When does problem-finding occur within the design problem-solving process?**
2. **What types of problem-finding occur in design and what roles do they play?**

**Significance of the Research Questions**

The research questions are significant for several reasons. Firstly, although the literature has acknowledged the existence of problem-finding, little attention has been devoted to exploring the types of problem-finding that are used during the problem-solving process. Most research is based on the assumption that problem-finding tends to happen only at the beginning of the problem-solving process (Dillon 1982; Reite-Palmon et al 1998; Jay & Perkins 1997). Current literature makes little mention that, while undertaking the solving of a problem, there may be additional problems that are found and used to solve the main problem. Understanding the kinds of problem-finding that may occur when designing, and the relationships between them, will advance knowledge of the process by which humans design.

Secondly, there is some evidence that the tendency to engage in problem-finding enhances performance on tasks where creativity is required (Getzels & Csikszentmihalyi 1976). Getzels & Csikszentmihalyi found that problem-finding among students of fine arts appeared to be a predictive measure of creativity. However, there
appears to be no research into how this may be achieved in general, and with high
school design students in particular. The only evidence of links between problem-
finding and creativity in reference to design cognition, appear to be in the area of the
fine arts (Getzels & Csikszentmihalyi 1976). The difference between problems in the
fine arts and design is that, unlike the fine arts, designing generally involves producing
an item that meets criteria for features such as function. Therefore, although a link has
been made between problem-finding and creativity in the fine arts, it is unknown if a
similar link can be made in high school designing, especially when the particular
characteristics of the subject area are taken into consideration. For example, industrial
designing has to allow for specific functional and safety considerations because the
realisations of the designs are to be used by people.

Thirdly, the research is important because we do not yet know if problem-finding is an
innate ability or disposition, or whether it can be learnt. The previous research by
Getzels & Csikszentmihalyi (1976), established a link between problem-finding and
creativity, but did not establish whether problem-finding could be taught or learnt.
Problem-finding may be an additional tool for teaching practitioners to teach creativity.

Lastly, possibly because there is a lack of cognitive literature explaining the role of
problem-finding in design, problem-finding is not generally recognised in curriculum
documents in terms of pedagogy (Queensland Studies Authority, 2004b). As a
consequence little is know about its role as a possible strategy that students may employ
in solving high school design problems. Hence, by addressing the research questions it
may be possible to gain insight into the role of problem-finding and its relationship with
creativity in high school design classes. Consequently, the findings of the research may
inform future curriculum and instructional development.
Problem-finding

In this section it is argued that there is a difference within the research literature, between the concepts of problem identification and problem-finding. The literature generally accepts the concept of the problem, as presented, and concentrates on identifying the categories of problems (Greeno 1978; Greeno & Simon 1988). Jay and Perkins (1997) have acknowledged the importance of identifying the type of problem-finding being studied.

Taking into account the type of problem situation is tremendously important because it affects what we mean by problem-finding and, consequently, affects how we interpret the processes. Differences in context may in fact call for different kinds of problem-finding. So whenever we speak of problem-finding, evaluate models, or interpret research, it is important to identify what kind of problem-finding is meant (Jay & Perkins 1997, p262).

Definition of problem-finding

To gain a clearer understanding of the research question a definition of problem-finding needs to be presented. Terms such as problem formulation, problem posing, problemizing, problem expression, problem construction, problem definition, and problem identification have all been used to describe problem-finding (Runco 1994; Runco & Nemiro 1994). All of these terms seem to refer to the process of initially identifying a problem to be solved. In designing, it is usually the recognition of the overall design problem to be solved. In contrast, it is argued in this study that problem-finding is a part of the act of solving the problem after it has been identified. Such an argument is supported by Michael (1977) and Getzels and Chikszentmihalyi (1976) who argue that problem-finding not only takes place at the beginning of the problem-solving process, but may also occur throughout the design process. Therefore, in this thesis problem-finding is defined as the process of questioning the nature of the problem as
identified and the process of finding other problems within the overall problem during the problem-solving process.

Problem-solving models have recognised the importance of identifying sub-problems when solving complex problems (Sternberg 1985; Rusbult 1989). However, most of the literature refers to the identification of problems prior to solving the main problem and not during the solving of the problem. This view is derived from information processing approaches to cognition (for example Newell & Simon 1972). In contrast, the types of problems that are examined in this study are problems that emerge during the problem-solving process and are not solely discovered at the start of it. That is, there is (a) the problem-finding that treats the problem, as presented, as propositional, and (b) the problem-finding that emerges as problem-solving progresses. These types of problems emerge as a function of the particular path the problem-solver takes, and the discovery of such problems in design can not always be foreseen. It is important to establish a clear distinction between these two ways of defining problem-finding because this research is focussed primarily on problem-finding that is unveiled during the solving of a problem and not the problem identification or the breaking down of a problem before commencing the solving process.

**Cognitive functions in problem-finding**

A review of the literature produced little empirical research on problem-finding, particularly in design. However, a longitudinal study on problem-finding in the fine arts undertaken by Getzels and Csikszentmihalyi (1976) recognised that problem-finding may be a more important characteristic or predictor of creativity than had previously been thought. This conclusion is in agreement with earlier speculation by Einstein and Infeld (1938), Henle (1975) and more recently, Dillon (1982).
Furthermore, after reflecting on his earlier work, Csikszentmihalyi (1994) wrote that:

Many creative individuals have pointed out in their work that the formulation of a problem is more important than its solution and that real advances in science and art tend to come when new questions are asked or old problems are viewed from a new angle… yet when measuring thinking processes, psychologists usually rely on problem solution, rather than problem formulation, as an index of creativity…They thus fail to deal with one of the most interesting characteristics of the creative process namely, the ability to define the nature of the problem. (Csikszentmihalyi 1994, p.138).

The framework for Getzels and Csikszentmihalyi’s (1976) study was based around the elements of creativity namely, the formulation of a problem, the adoption of a method for producing a solution to the problem and the actual solution itself. They wanted to see if a person who has to discover a problem, a method and a suitable solution is more creative than a person who has to adopt given problems, methods and solutions. Their research developed an analytical model for the correlation between Problem Situations and Cognitive Functions. The table is reproduced below as Figure 2.1.

<table>
<thead>
<tr>
<th>Problem Identification</th>
<th>Method of Solution</th>
<th>Solution</th>
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<tbody>
<tr>
<td>Problem Situation</td>
<td>Known by Others</td>
<td>Known by Individual</td>
</tr>
<tr>
<td>Type-1</td>
<td>•</td>
<td>•</td>
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<tr>
<td>Type-2</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Type-3</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>

□ = Unknown • = Known

**Figure 2.1: Correlation model between problem situations and cognitive functions**

(Getzels & Csikszentmihalyi 1976, p.80)
It can be seen in figure 2.1 that there are three types of problem situations, which Getzels and Csikszentmihalyi’s (1976) considered to be important. Type-1 problems restrict the person to using only memory as the main mode of thought. This type of problem is relatively simple and regarded as solvable by drawing on existing knowledge. The only unknown area is the solution to the problem by the individual solving the problem. For example: solve 6+3. The problem is defined. The method is addition and the individual need only determine that the answer is 9. Type-2 problems use reasoning and rationality as the main mode of thought. These problems are once again simple and closed. They differ from Type-1 problems in that the method and solution to the problem is known to others but not to the individual solving the problem. For example: If a dog has 5 bones and buries 2 of them how many does he have left? The problem is clearly defined. The individual must determine that the method is subtraction and that the correct answer is 3. Type-3 problems use imagination or creativity. All three areas are ill-defined to all. For example: How many important questions can be asked about God? (Discover Projects 2002). Getzels and Csikszentmihalyi’s (1976) research showed that when students pose their own problems (Type-3) they are able to access higher order cognitive skills such as imagination and creativity. This is important to this study because the design problem used in the experiment was composed to be a type-3 problem. The justification for this is that a more creative response, and hence more problem-finding, would be evident if a problem that allowed for creativity was presented.

Dillon (1982) went further and posed a conceptual scheme for comparing the levels of problem-finding and problem-solving. This is reproduced as figure 2.2.
Dillon’s scheme goes some way to defining problem-finding while at the same time relating problem-finding to problem-solving. In essence Dillon (1982) theorised three levels of problem-finding. They are:

1. Recognising obvious problems on the basis of knowledge in the field.
2. Discovering hidden problems on the basis of concentrated work in an area.
3. Inventing problems as a result of reorganising existing knowledge.

According to Dillon (1982), problem identification can be taken to refer to activities that occur before the problem-solving process begins.

The first step in most schemes of problem-solving is, simply, a given problem. That step may accordingly be viewed as the last step of problem-finding, that process which eventuates in a problem to solve (Dillon 1982, p.103).

Although Dillon (1982) theorised different level of problem-finding, they were focussed on problem-finding that happens before problem-solving begins and not during problem-solving as is the focus for this study.

In contrast to Dillon’s argument, it is argued in this thesis that there are at least three factors that support the view that the act of problem-finding does not end when problem-solving begins. Firstly, problem-solving is a process that is cyclic in nature (Suwa et al 2000). Secondly, problem-finding can occur after problem identification has been completed (Michael 1977). Thirdly, problem-finding is a part of the problem-
solving process and not distinct from it (Getzels & Csikszentmihalyi 1976). Hence this study clearly distinguishes between problem identification as the initial, and usually, formal representation of a problem and problem-finding.

What is not evident from the literature is the notion of problem-finding as defined in this study. Michael (1997) and, Getzels and Csikszentmihalyi (1976) did acknowledge that problem-finding does occur during the solving stage but failed to elaborate:

“Problem-finding continues throughout the creative process and may continue even after the work is completed and the problem ostensibly ‘solved’.” (Getzels & Csikszentmihalyi 1976, p.90).

**Problem-finding and creativity**

Getzels and Csikszentmihalyi’s (1976) study found that a person who uses problem-finding effectively would be more creative than a person who does not. The study also identified the traits of an effective problem-finder in the fine arts. Some of these are:

1. The ability to keep the structure of the problem from crystallising too soon.
2. The ability to use many problem-solving strategies.
3. The ability to never believe that a problem is solved and that it cannot be altered any more. (Getzels & Csikszentmihalyi 1976).

Getzels and Csikszentmihalyi’s study identified the characteristics of a good problem-finder. The study did not, however, examine the types of problems that may exist when a person is solving a problem or in the case of art, creating a piece of artwork. Thus, a question that remains is concerned with the links between the problems and the ways in which identifying and solving them contributes to the solution. Getzels and Csikszentmihalyi’s study showed a link between problem-finding and creativity.
However, the study did not attempt to explain why or how problem-finding enhances creativity. If it can be shown that problem-finding in the fine arts helps to enhance creativity, how then can it be applied to the education of high school design students whose designs differ to the fine arts by having a need and a practical application? Do teaching strategies exist which can be applied to help students engage problem-finding that enhances creativity and allow them to access, utilise and develop their higher order thinking skills?

Researchers such as Hoover and Feldhusen (1994) and Getzels and Csikszentmihalyi (1976) have recognised that part of the reason for a lack of research on problem identification is the difficulty in setting up the situation of problem identification so that it can be examined in a specific context. How can you study a person who is trying to identify a problem to solve when the person you are studying doesn’t even know a problem exists? How do you study a person who has to identify a problem in an ill-defined context without telling them there is a problem? How do you know when they have identified a problem? These are all difficult questions to answer and are justification for the scarcity of research on problem identification.

**Categories of problem-finding**

Although Getzels and Csikszentmihalyi (1976) did acknowledge the existence of problem-finding, their work was more concerned with problem-finding as a personal characteristic or tendency of particular problem-solvers. Getzels and Csikszentmihalyi did not explore the different types of problem-finding that could happen during the problem-solving process.
This study argues that various types of problems exist in designing and that finding them and solving them are important creative processes in design. By analysing subjects undertaking a design task, this study hypothesises four categories or types of problem-finding which were derived from theoretical models (Points 2 and 3 below) and also developed from the protocols in this study (Points 1 and 4 below). The study argues that each of these problem-finding categories plays an important and yet largely unreported role in the solving of creative problems, in general and design problems in particular.

They are:

1. Clarification, (Protocol derived)
2. Elimination, (Yashin-Shaw 2001)
3. Exploring ideas, (Finke, Ward and Smith 1992)
4. Lack of Knowledge, (Protocol derived)

Each of these points is elaborated on further in Chapter 3 by including examples from the transcripts. However, because the categories were an important area of this study a brief introduction to them is presented.

Point one, Clarification, was derived from examining the protocols of the subjects studied in the experiment. Clarification in this study is defined as when a designer clarifies the initial given problem to be solved by finding sub-problems that need answers. The clarification must refer back to the original initial problem presented.

Point two, Elimination, was derived from a theoretical background, which was grounded in Yashin-Shaw’s (2001) study of creative thinking. She defined Elimination as the rejection of an idea due to its irrelevance, uselessness or impracticality (Yashin-Shaw 2001, p.120). This study has modified this definition to be more problem-finding
oriented. The definition used in this study is that Elimination is where the designer eliminates a solution to a problem by finding a problem that makes the proposed solution unusable.

Point three, Exploring ideas, is based on Finke, Ward and Smith’s (1992) Geneplore model. Although their model consisted of several procedures to describe the notion of exploration, this study has encapsulated the overall meaning of exploration. Exploring ideas is where the designer adds to the solution by finding a problem with the current solution. As they are designing, they find a problem with a part of their solution and use this to build and refine their ideas.

Point four, Lack of Knowledge, was derived from the protocols in this study. It is defined as when one is unable to solve the problem through a lack of technical knowledge. The problem found here is that the designer doesn’t know how to solve the problem because they can not find a solution. In essence the designer has found a problem because they don’t know how to progress any further with their design.

In summary, evidence has been provided to suggest that there is a relationship between problem-finding and creativity and that problem-finding may be an important aspect of creativity. Problem-finding was defined as the process of finding other problems within the overall problem during the problem-solving process. It was also argued that problem-finding may be studied because it is one step of the problem-solving procedure that is cyclic in nature and occurs after the problem is identified. Furthermore, this section argued that various types of problems exist in designing and that finding them and solving them are important creative processes in design. The section provided and
explained the inclusion of four categories of problem-finding that were used in the study.

Having established what problem-finding is, it is useful to understand also what designing means. This is important because this study is interested in identifying relationships between problem-finding and designing. Therefore, the next section explains the nature of design as it relates to this study.

**What is design?**

Two terms that are used to describe the development of new ideas are invention and design. Both terms are often used interchangeably and the meanings ascribed to each are often confused. Inventing is the making of new ideas or articles, while designing could be described as the drawing or sketching of objects that are then to be built or manufactured (Cognitive Science Laboratory 2004). There are various definitions for each but in terms of cognitive processes, it is difficult to make a distinction between the two. In this study design will be defined as including the cognitive processes to be found in invention.

Design in itself is a concept that is often misunderstood (Gardner 1978). Therefore, a clearer understanding of what design means to this study is required. The word ‘design’ is used in many contexts and is capable of being defined in different ways. The concept of designing does, however, portray an element of creativity used in an environment of inventiveness and imagination (Gardner 1978). Jones (1991) stated that;

…there are many new ideas of what designing is. All are very different:

- designing as the process of devising not individual products but whole systems or environments such as airports, transportation, hypermarkets, educational
curricula, broadcasting schedules, welfare schemes, banking systems, computer networks;
- design as participation, the involvement of the public in the decision-making process;
- design as creativity, which is supposed to be potentially present in everyone;
- design as an educational discipline that unites art and science and perhaps can go further than either;
- and now the idea of designing without a product as a process or way of living in itself. (Jones 1991, p.5)

In addition, Alexander suggests that design “is the process of inventing physical things which display new physical order, organisation, form in response to function” (Alexander 1964, p.4). In contrast, Dasgupta (1996) has difficulty agreeing with this single definition due to the ambiguity of the word ‘function’ along with a lack of explicit mention of desirable goals for design such as reliability and performance. Dasgupta (1996) proposes that although design is a process, it is fundamentally an act of creative cognition, and the extent of that creativity will vary from one situation to another. Torrance (1964) also provided some evidence to link creativity with newness by arguing that it is impossible to be creative without being original. If something is new it is also original. Hence, the desire for newness is a condition needed for the design process to occur. Therefore without newness a person would simply be reproducing a known solution to a problem. This is commonly the theme with many high school design projects. The Australian National Technology Statement of 1994 emphasises the importance of developing creativity and imagination in students.

A process of designing, making and appraising involves students in investigating, devising, communicating, producing and reflecting. Through this process students develop ideas and create imaginative solutions for the learning tasks in which they are engaged. They participate in decisions about what to do, why it should be done, how it should be done, and how what has been done might be improved. Particular attention is given to the context in which the tasks and activities are set. (Technology Education Federation of Australia 1999)
Design is also becoming more complicated in the way it is delivered. Newer understandings about how we design bring about more difficult issues such as what role originality plays in design and what type of problems can be solved using original ideas?

Hutchinson and Karsnitz (1994) identified that problem-solving in high school Technology Education subjects may more accurately be called designing due to the confusion associated with the definition of inventing and designing. They view design as being:

> a strategy used to clarify, investigate, develop, make, test, evaluate and improve solutions to problems with many possible ‘correct’ answers...Unlike other areas of formal education, these real-world problems lead to solutions which have many possible answers, all with trade-offs and varying degrees of risk (Hutchinson & Karsnitz 1994, p5).

It is acknowledged that there are many ways in which design is defined and some of these are contradictory. This study adopts Hutchinson and Karsnitz (1994) definition of design because their definition corresponds to the kinds of activity undertaken as design in schools. Moreover, the focus of this dissertation is more concerned with the thinking process in design than defining design, and design thinking is examined in the next section.

**Design thinking**

This section argues that creativity is an important aspect of designing and that creative designing may be learnt. Therefore if creativity may be learnt, the act of problem-finding maybe learnt also.
During the 1930’s Rossman (1964) conducted a study in America which focused on understanding the characteristics of inventors and the psychology of the invention process. One aspect of the study was to identify the characteristics of an adult inventor. Rossman used a sample of 864 successful male inventors. The sample was made up of 176 Patent Attorneys, 78 Directors of Research, and 710 people who described themselves as inventors but who had not produced any papers. Overall, the sample was considered to be a highly successful group because on average each held 39.3 patents. The subjects were asked to respond to a questionnaire, which included one question that asked them to name the ‘mental characteristics of inventors’. There were three common characteristics that were identified by all participants: originality, perseverance, and imagination. Rossman (1964) also suggested that the responses from the inventors were the most valid and reliable because they had elaborated on their responses when compared to the others and the sample was larger than the others. The responses from the inventors suggested that they believed that originality, perseverance and imagination could be developed. In addition Rossman noted that 63.4% of the patent attorneys had patented their own inventions and this led him to believe that contact with inventions could stimulate invention (Rossman 1964).

Rossman was interested in finding out if the inventing process could be learned. He concluded from the respondents remarks that, “Inventing is a learned behaviour and there is no evidence whatsoever to indicate that it is intrinsic” (Rossman 1964, in Westberg 1996, p.256). These findings are important to this study because they provide evidence to suggest that inventing or designing is a cognitive behaviour and that this behaviour can be modified. What is currently unknown is how this behaviour might be changed and if there are important aspects of current approaches to designing or the teaching of design that need changing to effect the changes. More specifically, in the
context of this study, is the role of problem-finding, whether it assists designing, and whether it can be learnt.

Using some of Rossman’s findings, Westberg, (1996) conducted a study of primary school students (grade 4 to grade 8) into the effects of teaching students how to invent. Whereas this study is focusing only on the area of problem-finding, Westberg’s study dealt with the whole process of inventing. Her study developed the Invention Evaluation Scale to assess three aspects of students’ inventions: originality, technical goodness, and aesthetic appeal. Westberg’s study involved using control and sample groups to see if there would be any difference, by way of number of inventions, between the two groups when one is subject to eight lessons on inventing and the other is not. The third of the eight lessons that was delivered to the sample group focused on the crux of this research paper— problem-finding. The lesson is described as;

**Objective:** To begin the first step in the invention process, identifying a need or want.

**Description:** Students learned problem-finding techniques and began compiling a ‘bug list’. Students discussed the meaning of the Einstein quote: The identification of the problem is more important than the solution, which may merely be a matter of mathematical or experimental skills. (Westberg 1996, p.257).

The results indicated that as little as one introductory lesson designed to stimulate an interest in inventing could motivate students to complete the development of an invention. However, Westberg’s study did not identify which of the eight lessons would have most impact on a student’s ability to invent. Therefore, it is unknown how much impact the third lesson on problem identification had on the students’ ability to invent. Westberg’s (1996) work contributes to this study by providing evidence that inventing can be learnt and hence taught, and that the effect of teaching for problem identification may well have been of benefit to designing. In the same way, problem-finding as defined in this study may also be able to be taught and learnt. What is unclear is how
this is achieved and what role problem-finding plays in the inventing /designing process. Therefore, this study will attempt to discover if problem-finding activity can be identified and what effect such problem-finding has on the design process.

In summary, the literature describes designing in many different ways such as designing, invention, creativity and originality. This study acknowledges that designing encompasses all four descriptions but argues further that creativity is an important underpinning feature of all aspects of design. Design and patent rules require that, for an object to be registered as a design, they must include a proportion of original design. The literature also provides some evidence to suggest that inventing or designing is a learned behaviour that can be taught and that problem-finding may be an important component of good designing. What is not evident from the literature is what role problem-finding plays in the design process. Answering this question is one of the aims of this study. The next section is concerned with examining different design methods used by designers and students in schools.

**Design methods**

Stempfle and Badke-Schaub (2002) discuss three strains of design thinking. They term them the normative strain, the empirical strain and the design-as-an-art strain. The normative strain is focussed on a systematic design method to solve a problem. The designer uses a set of guiding principles to solve the problem. The empirical strain rarely follows any of the normative principles. The empirical strain questions whether designers use any methodology at all. The design-as-an-art strain is based around the notion that designers are like artists and apply different design principles depending on the design problem at hand. The following section presents a brief examination of these principals to provide a perspective on professional design that may then be used to
develop a comparative view of how designing is undertaken in Queensland High Schools.

Pahl and Beitz (1984) have classified designing into three categories: original designs, adaptive designs, and variant designs. Original designing involves the expansion of an original solution principle to perform the same, similar or new task. Adaptive designing requires the application of a known system to change a task while the solution principle remains unchanged. Variant designing requires a change in size and arrangement of some aspects of the chosen system while the solution principle remains the same.

In addition to the above-mentioned categories, Sivaloganathan, et al (2000) argued that there are two methods for approaching the design and development of a product. They are the systematic and the conventional approaches. The systematic approach breaks down the design process into a set of small tasks. Each of these tasks is enhanced by the use of special design methods or design tools. Alternatively, the conventional approach is founded in firstly, understanding the design brief; and then possible solutions are identified, and a model is built, tested and modified. This cyclic procedure continues until a suitable design is reached (Sivaloganathan et al 2000). The main difference between the two approaches is that in the systematic approach, the thrust is based around data gathering and predicting what the design will look like. The conventional approach is more instinctive and focused more on an experimental or trial and error approach, which allows for a progressive development of design ideas.

Sivaloganathan, et al (2000) experimented with both methods to test which was the easiest way to develop new products. They conducted an experiment using the two different design methods. The experiment involved having a team of university students
use either the conventional or systematic approach to design a disposable bicycle made out of paper. They concluded that for their experiment, a hybrid of both approaches was the easiest. This is explained as follows. The systematic approach would be better suited to designs that are new products, which are clearly defined and have data and information available. They also found that this method worked better if the article being designed was a variant of an existing product such as airports or shopping centres. The conventional approach was found to be suited to designs which had little or no available data, were not clearly defined and were almost completely original, for example a piece of machinery. The design problem that was used in the experiment was both a variant of an existing article, a bicycle and also original in that it was made from paper. This would appear to reinforce their findings of a hybrid method as the most suitable due to the combination of design properties from each of the approaches.

From the Sivaloganathan, et al (2000) experiment it would appear that each aspect of design has its own method and that the methods can be used independently or in unison. The experiment also highlighted the reliance placed on the designer to know how and when to apply different design methods to suit the situation during the design process. The many varying concepts of design may require different methods to solve problems adequately, and conversely, the type of design problem may dictate the type of method needed to solve it. Therefore, Original designing may require a different type of process to be able to identify problems than Variant or Adaptive designing, and the type of strategy used to identify design problems may vary according to the type of designing or design method employed.

For these reasons, it is argued here that it is important to gain an understanding of the different types of design methods that are used because this may have implications
regarding the types of designing undertaken in the high school context. If the use of a variety of different design methods is important, then the question arises of where does the concept of problem-finding belong within the design process, and does the design process have an effect on problem-finding when applied to high school students?

The school level

In Queensland high schools, students have the opportunity to study design through two design based subjects, Technology Studies and Engineering Technology. Both are two-year subjects that become part of a student’s final year 12 matriculation. The type of design that is involved would normally range from the designing of furniture through to designing machinery or model bridges. The approach to designing taken in each of the subjects varies in different ways. Technology Studies emphasises the importance of a pre-set design process or systematic approach described earlier, whereas Engineering Technology uses a trial and error or conventional approach. The difference between the two study areas is that in Technology Studies the students are assessed on their ability to demonstrate how they arrived at their designs. In Engineering Technology the students are only assessed on the finished product’s effectiveness in solving a given problem. The reason for this is that, in Engineering Technology, the problem is given to the students, and in Technology Studies, the students have to identify their own problems to solve.

Lewis et al (1998) would criticise the stance taken in Technology Studies by suggesting that the practical application of a pre-specified design process or systematic approach in the classroom would neutralise creativity. They argue that the use of design methods has become a classroom ritual, which has more to do with the classroom culture than solving a design problem. The differences between the subject areas are important
because one subject may use different problem-finding techniques than the other to solve design problems.

The Queensland curriculum encourages the use of designing as one of the many areas a student is finally judged on at the end of year 12. This is intended to emphasise the importance of designing, not only at the school level, but also for the world of work. It is essential to understand that this study is not centred on the design process but on the underpinning notion that problem-finding is one subset of the design process and that problem-finding may encourage creativity. Lewis et al (1998) agreed with this because they and others such as Csikszentmihalyi (1994) and Hill (1996) provide evidence that problem-finding is related to creativity. What is unknown from the literature is: what are the specific relationships between problem-finding and creativity in designing? To examine this it is important to firstly gain an understanding of some cognitive processes being utilised when designing.

**Cognitive processes for designing.**

A review of the literature was unable to locate research findings into the instructional strategies used by design educators to encourage problem-finding in students. This is reiterated by Oxman (1999) who states that:

> The cognitive properties of design learning have never been the subject of design education. As a consequence, there presently exists a lack of educational theories of learning which function as an underpinning of design education. (Oxman, 1999, p.107).

Historically research has been able to identify what designers do but has been less successful in identifying how they do it (Eastman 1999). Early research in design cognition viewed designing as a form of problem solving which was approached in a
similar manner to studies in chess or puzzle solving. It was soon realised that design
problems are different to chess or puzzle problems in that they are ill-defined, ill-
structured and therefore may use different cognitive processes (Eastman 1999).
Although there is no literature explicitly on problem-finding strategies in design, the
literature does explore some of the cognitive processes relating to the identification of a
problem when designing. For example, Dorner (1999) describes the journey of
designing a machine from idea to realisation. He starts off:

In the beginning there is a cloud! When designing begins
there exists a more or less cloudy idea about how the
machine should look and how it should work. This cloudy
idea crystallises in the course of time and is transformed into
a clear and complete image of the machine in the form of an

Dorner attempts to answer questions relevant to this research such as: Where does the
design cloud come from, when does the process of crystallisation of the design cloud
happen? He suggests that one means of identifying the cloud could be from past
experiences with similar designs. This linking of past experience or knowledge with a
design problem can be a catalyst for the generation of the initial idea. In addition, he
also warns that:

Experience generally encourages conservatism and may
sometimes fence the design process in the (more or less)
narrow bounds of the past, thus inhibiting the formation of
new ideas. Experience can be a great help, but it can also be
a barrier to new developments. (Dorner 1999, p.408).

This review suggests that design problems that are unfamiliar may result in a better
outcome. Designing using past experiences is linked with and Pahl and Beitz’s (1984)
principles of Adaptive and Variation designing. It seems not to be linked with the notion
of Original designing because unlike Adaptive and Variation designing, the solution
principle generally would not be known to the designer because there should be no
substantial past experiences associated with Original designing. An implication of
Dorner’s identification that past experience can limit originality and innovation in design is that 15 and 16 year old students may have the ability to apply the principle of original designing because they generally do not have a vast amount of past experience due to their age.

Herschbach (1998) discusses different types of knowledge from a constructivist perspective. He recognises that there are different kinds of knowledge stored in long-term memory. They are termed Declarative, Procedural and Conditional knowledge and all three forms are thought to require different learning and hence teaching strategies. Declarative knowledge is described as a collection of facts or information, sometimes described as ‘knowledge that’. Procedural knowledge involves the process of transforming information or knowing when to do something, sometimes described as ‘knowing how’. Conditional, or strategic knowledge includes knowing when to apply a given cognitive strategy as well as why it should be applied.

In the same vein, Oxman (1999) proposed an educational model based on learning through the structuring and manipulation of knowledge rather than the traditional classroom based models. That is, that evaluation is based on a measure of increments of knowledge acquired rather than the final product. He argued that gaining a deeper understanding of relevant concepts of design thinking through constructive processes may provide an alternate medium for design thinking.

In summary, the past experiences and the type of knowledge that a person uses to solve design problems may influence the process and final outcome. Likewise, the way in which a person uses problem-finding to solve design problems may also be dependent on the type of knowledge they use. Therefore, if the cognitive processes used by a
person to solve design problems is important, it may also be possible that providing particular instructional strategies can produce more creative designs. People may be able to use metacognition to be aware of the processes they are using when designing and in turn produce better designs. To gain a better understanding of creative designing, the following section examines relevant literature on originality and creativity.

**Originality and creativity**

Literature on originality and creativity are reviewed here for three reasons. Firstly, creativity appears to be related to design; secondly, originality appears to be a component of creativity; and thirdly, problem-finding may improve creativity. Therefore by drawing on the findings of studies on originality the relationship between originality and creativity in designing can be further developed.

**Kinds of creativity**

Boden (1990, p.32) proposes a distinction between what she calls “psychological creativity” (P-creative) and “historical creativity” (H-creative). P-creative is when a person has an idea that is novel for that individual. H-creative is when an idea or thought is novel when compared to the whole of history. Therefore, Boden is saying that creativity is a property of the product of one’s own mind and is synonymous with novelty. Dasgupta (1996) takes this notion further by being able to distinguish between four levels of creativity.

- **Psychologically Novel (PN-creative):** is where a person believes that within their own personal knowledge body there is no other idea or artifact that is identical to it.
- **Psychologically Original (PO-creative):** is where a person believes that the idea or artifact adds significantly to the relevant community’s public knowledge.
- Historically Novel (HN-creative): is where the relevant community believes that no other identical public knowledge exists.
- Historically Original (HO-creative): if in addition to the previous levels, the community agrees that the idea adds significantly to its body of knowledge.

Dasgupta makes the point that “… a design process becomes (or is) an act of true invention when its output – a design – is deemed psychologically original by the designer or historically original by the relevant community.” (Dasgupta 1996, p.65)

For the concept of designing to have an element of creativity (as mentioned by Gardner (1978) at the beginning of this chapter), the notion of originality, for the students, could be determined by either themselves or their design class (as the community by which judgement is made).

**Promoting originality**

Early empirical work by Slosson and Downey (in Maltzman 1960) tested for originality by analysing the writing of plots. They issued their subjects unusual messages found in the personal columns of newspapers. The subjects then had to write plots or stories based on the newspaper clippings. Their simple test for originality was to determine how many different plots could be written to the same message in a given time. The theory behind the study was that the “writer is forced to practise literary invention… This form of mental gymnastics will increase the originality of his writing.” (Slosson & Downey 1922, in Maltzman 1960, p.231). Osborn (1957), the inventor of what is now commonly termed Brainstorming, also believes that originality can be trained. He agrees with Slosson and Downey in “that practice in producing original ideas will further develop originality” (Osborn 1957, in Maltzman 1960, p.231). Osborn’s
Brainstorming procedure allowed for people to develop many ideas without criticism or judgement as to their value. Osborn believed this approach would allow for many ideas to be presented and would avoid inhibiting unusual or original ideas.

It is evident that the early research on originality stressed quantity of ideas. These researchers believe there is a direct correlation between an idea being original and the quantity of ideas generated. Unknown from the literature is the relationship between problem-finding, idea generation and originality.

**Teaching originality**

Maltzman (1960) used two tests to find out if originality could be taught. The results of his tests showed that minimal training and instruction produced a significant increase in originality on the Free Association Test List and the Unusual Uses Test for Originality (Maltzman 1960). Maltzman believes that the problem with training for originality is to devise a means of increasing the rate of recurrence of uncommon behaviour. His research showed that once original behaviour takes place, aided by positive reinforcement, it may increase the probability that more original behaviour would happen. In essence he argues that a person can learn how to be original by being exposed to original thoughts. This is similar to Rossman’s belief that contact with inventions and inventor’s thoughts can stimulate the act of inventing (Rossman 1964).

In contrast, Joy (2001) conducted a study using similar testing instruments to Maltzman. Joy’s experiment differed in that the subjects were not trained or given reinforcement on originality. The results showed that there was an increase in the originality scores for his sample. Both Maltzman’s and Joy’s studies indicate that the respondents did become more original during the experiment, but the lack of training and positive reinforcement
in Joy’s experiment makes it hard to judge whether the training in Maltzman’s study did in fact enhance originality. This research is important to this study because it confirms that inventing or designing ability may be enhanced and that creativity may not be innate. Other than positive reinforcement, the literature fails to state how originality can be enhanced or if there are certain aspects to designing that can enhance originality. Problem-finding may be an important component that, as yet, has not been recognised.

The research in this dissertation is concerned with the role of problem-finding in enhancing creativity and performance in design with children, an area in which minimal study has been undertaken. However, de Bono (1970), who has done some work in this area, tends to agree with Maltzman (1960) by saying that:

> If an idea is silly an adult will throw it out. But because a child does not throw it out it can become useful. The idea itself may still remain as silly as ever but it can set off new ideas. In any subject silliness is a judgement based on limited knowledge. (de Bono 1970, p.122).

De Bono (1970) is arguing that the generation of ideas can bring to light other ideas.

In summary, Dasgupta (1996) believes there are four levels that can be used to judge creativity. Others such as Slosson and Downey (1922) believe it may be possible for a person to become more creative by increasing the number of ideas generated, and they may learn to produce original ideas by being exposed to original thoughts. Researchers such as Maltzman (1960), Osborn (1957), Slosson and Downey (1922), and de Bono (1970) all agree that one of the keys to creativity is the generation of many ideas and that this inherent skill can be trained. Are students being taught how to think creatively? Are they encouraged to have ‘silly’ ideas? It is argued here that students need to have the freedom to explore as many ideas as possible to solve the problem. If they are later identified as ‘silly’ or unworkable they can be eliminated. If they have some value they
can be expanded upon. This should enhance the creativity of the design. This study argues further that there may be similar links between an increase in creativity and the number of problems a student can find whilst solving a design project. Therefore problem-finding may play an important role in creating good designs. The concept of problem-finding is expanded next through the presentation of theoretical models associated with cognitive aspects of problem-finding.

**Theoretical models of design problems**

This section looks at three theoretical models associated with creative thinking to investigate how designers solve design problems. The section firstly looks at a problem-finding model and then incorporates two models of design thinking.

Hoover and Feldhusen (1994) studied problem identification by gifted students. The way Hoover and Feldhusen defined problem identification suggests a definition consistent with that used to define problem-finding in this study. That is, “…problems where the solver must clarify the structure, establish the parameters of the problem space, and eventually design the problem to be solved. In essence, the individual must find the appropriate or essential problem.” (Hoover and Feldhusen 1994, p.208).

Hoover (1990) proposed a theoretical model as an introduction to the study of scientific problem-finding ability. This is presented as figure 2.3.
Three components of the model have been explored extensively in a science based context. These comprise memory organisation/facilitation, metacognitive skills, and specific and general skills (Hoover & Feldhusen 1994). The fourth area of extra-cognitive skills, attitudes, motivation and interest has not been adequately explored in a problem-finding design-based context.

The Hoover and Feldhusen (1994) research provides evidence to suggest that problem-finding is not related to intelligence and aptitude and therefore suggests that the act of problem-finding may be learnt. A conclusion that can be drawn from the Hoover and
Feldhusen research is that learning for problem-finding may be delivered through developing students’ extra-cognitive skills such as attitude, motivation and interest in their designs. Likewise, Hidi (1990) claimed that the level of interest a person shows in a problem might be related to creative responses. Based on these two conclusions, it is argued in this study that the level of interest a person shows in a problem may enhance the creativity of the solution. Therefore, encouraging students to undertake design tasks that they are interested in, may lead to the students becoming better problem-finders and hence more creative designers.

Middleton (1998) proposed a model of a problem space that incorporates the demands of design problems (Figure 2.4).

![Figure 2.4: Problem-solving model (Middleton 1998, p.32)](image)

His model identified what is called the Search and Construction Space. This is the area of the problem space that a designer would ‘travel’ through, or navigate, to reach a goal or the Satisficing Zone. Middleton argued that the Search and Construction Space in design problems is complex and opaque, and for that reason, the diagram represents a variety of solution paths. Stempfle and Badke-Schaub (2002) further add that when compared to domains such as the arts, the Problem Zone in design is much less flexible. The reason for this is that:

...requirements and constraints are mostly fixed and can only be negotiated to a certain degree. Discrepancies between different requirements are not an exception, but the rule — for example, a motor should at the same time provide
optimum performance, but take up very little space. (Stempfle & Badke-Schaub 2002, p.475)

In addition, they argue that the Satisficing Zone is similar in both the arts and designing in that: “There is rarely simply one single solution — there are many possible solutions, with every solution representing a trade-off between certain advantages and disadvantages.” (Stempfle & Badke-Schaub 2002, p.475).

What is unclear at this point is what are the procedures that designers use to move from the Problem Zone to the Satisficing Zone. Could problem-finding be a mode of getting from one zone to the other? With more limitations placed on the Problem Zone in designing than in art, and with the knowledge that problem-finding does exist in the fine arts (Getzels & Csikszentmihalyi 1976), it is important to find out the nature of problem-finding in designing.

The Geneplore Model (Figure 2.5) proposed by Finke, Ward and Smith (1992) is one possible suggestion for moving from a problem to a solution. Their model highlights the notion of generative and explorative processes. These processes could be seen as a means of moving through the Search and Construction space depicted in Middleton’s (1998) model. In the Geneplore model a person would cycle between the generative and explorative stages. The generative stage is where knowledge is recalled, associated or transformed. The explorative stage is more organised than the generative stage in that it takes the information from the generative stage and places it within a context, or places limitations on the information. The explorative stage may lead directly to a creative product or to a return to the generative stage for further modification. As the diagram indicates, product constraints are imposed from outside the generation-exploration cycle but are able to be imposed at any time until a solution is reached (See also Yashin-Shaw 2001).
Figure 2.5: Geneplore model (Finke, Ward and Smith, 1992, p.18)

It is hypothesised that by placing the Geneplore model inside Middleton’s (1998) model, a clearer picture of the cognitive processes being utilised along the undefined pathway between the Problem Zone and the Satisficing Zone might be gained. That is, this study hypothesises that problem-finding, as defined by this research (and exemplified in the Geneplore model), may be another set of cognitive procedures that could strengthen the understanding of creative thinking by providing an avenue to move from a problem to a solution. That is, by developing such problem-finding skills, a person may be able to solve design problems more easily, and may be inspired to try more difficult designs or come up with better ideas.

Conclusion.

In this chapter it is argued that the term problem-finding is often used to refer to the initial identification of a problem. This thesis poses that problem-finding is the discovery of problems whilst solving a problem and that the process of problem-finding
may continue throughout the solving of the problem. Problem-finding is further clarified as both the detection of difficulties and also the finding of new questions for scrutiny.

By considering the above-mentioned issues the chapter has presented and justified the Key Research Questions which are:

1. **When does problem-finding occur within the design problem-solving process?**
2. **What types of problem-finding occur in design and what roles do they play?**

The questions are justified by arguing four main points: Firstly, that there may be different types of problem-finding; secondly, although there has been a link made with problem-finding and creativity in the fine arts, it is unclear if a similar link can be made in high school design given the nature of the subject; thirdly, it is not known whether problem-finding can be learnt; and lastly, because little is known about problem-finding, curriculum documents fail to recognise it.

Further, the chapter argues that designing can be described in many ways and that the underpinning feature of most aspects of design is creativity. Evidence was also presented that designing may be learnt, and that problem-finding may be an important component of designing which may also be learnt.

The chapter also examined different design methods and discusses how a designer may need to choose a method to solve a problem based on the type of problem they are solving. This is important because it may have implications regarding problem-finding and the type of design methods taught in schools.

Some studies suggest that increasing the frequency of idea generation may enhance a person’s ability to be creative. It is also argued that problem-finding ability is an
important measure of a person’s creative capacity and that a creative person would possess the capability to problem-find more so than others. Whether this capacity can be learnt and how it can be developed and increased is unclear in the current literature.

In addition, the Chapter introduced the four problem-finding categories that were used in the study. The categories were contextualised in the study through providing a succinct definition of problem-finding.

Finally, the chapter examines models of design thinking and argues that problem-finding may be a mechanism for designers to navigate through the clouded and often complex pathway from problem identification to solution. It is suggested that, by further understanding problem-finding, designers may be able to develop their designing skills and produce better designs more easily. In the following chapter, the method by which problem-finding was operationalised into the study is presented. The section describes how the research questions were investigated and analysed.
Chapter 3: Methodology

Introduction

The aim of this study is to examine the role that problem-finding plays in enhancing creativity in high school design classes. As outlined in Chapter 2, the role of problem-finding in this study is examined through two questions which are:

1. When does problem-finding occur within the design problem-solving process?
2. What types of problem-finding occur in design and what roles do they play?

This chapter operationalises problem-finding into the study by presenting and justifying the research method used to address the two questions. The chapter is structured in the following way. Initially, the chapter examines different types of research methods used to study design. Then the Think Aloud method, as it is applied to this study, is elaborated on. Following this, the data analysis method is discussed and finally the strengths and limitations of the study are presented.

Previous studies in problem-finding have suggested that the context of a problem may make a difference in why and how problem-finding occurs (Jay & Perkins 1997). For instance, do people who undertake problem-finding in mathematics use a different kind of problem-finding than someone who is designing? Researchers such as Runco (1994) and Dorner (1999) have raised the need for observational subject studies and in-depth protocol studies of problem-finding behaviour. Therefore to enable the act of problem-finding to be identified in designing a suitable method for capturing problem-finding in a contextualised design activity was required. This research used a Think Aloud verbal protocol elicitation method of collecting verbal protocols from three high school design students and one high school design teacher.
The literature review presented in Chapter 2 argued that problem-finding can be both the detection of difficulties and the finding of new questions to be answered (Getzels 1982). It also argued that problem-finding is more than simply the discovery of an initial problem to be solved. To explore these ideas it was necessary to devise a method that would allow for the collection of data grounded in the thinking processes of people engaged in designing. Paivio (1979) argued that thinking can be represented in memory both visually and verbally and that both of these may occur at the same time. In designing, some form of sketching is usually used to communicate and consolidate thoughts and ideas. It is argued that because designing involves complex information processing, represented in more than one modality, that verbal or visual data alone are not sufficient to encapsulate the notion of problem-finding by designers. Hence, by capturing both the verbal and visual thoughts a more comprehensive and useful set of data may be obtained. Therefore, it was necessary to design a method that could collect the data in a manner that would allow for both verbal and visual thinking to be captured. To achieve this, the study used the Think Aloud method (Ericsson & Simon 1993) where data is collected by videotaping the sketching process of people designing, as well as their talking while designing.

The following section firstly presents a description of some methodologies that have been used in previous design research. It argues for the adoption of the Think Aloud verbal protocol method as the preferred option for the study. This is achieved by outlining the strengths and weaknesses of other methods and by giving justification for the elimination of these methods.
Design research methodologies

The methods employed in design research have been diverse. The relatively small amount of empirical research that has been conducted on design thinking has used mainly three methodologies. Cross (1999) summarised these as: structured interviews, observations, and protocol studies. To date, none of them have been used to study problem-finding in design. The following discusses each of these methods in turn.

Structured interviews

According to Cross (1999) structured interviews with designers have usually been associated with experienced people who have a well-developed design ability. However, this study is focused on high school students who are not experienced designers and who do not have a well-developed design ability. Interviewing does allow subjects to reflect on their thinking; however, this method could result in the data being suspect due to the lack of real life design tasks that the students would have been exposed to and their ability to discuss using adequate terminology. The students may have difficulty being able to reflect on the design processes or procedures that they are using because, unlike an experienced designer, the student would have had little exposure to such methods of operation. In addition, designing is regarded as a cognitively demanding activity (Middleton 1998); therefore students’ inability to discuss design processes in real life situations would make the use of structured interviewing as a methodology for high school students questionable. In addition, interviews have the problem that being after the event they suffer from limitations in subject’s memory and the tendency, noted by Ericsson et al, (1993), for accounts to represent what subjects would like to think they were thinking, rather than what actually occurred.
Observations
Observation has also been a useful method for gaining insights into the processes a person utilises in solving a single design project. The method allows for close analysis of a designer’s immediate thoughts as reflected in the sketches or drawings they generate. This method requires close observation of a particular subject and hence may require a large amount of time to collect the data. The method, while apparently effective, may be impractical for this study. The reason for this is that the school environment involves classes of 20 – 25 students undertaking 50-minute lessons. This means that being able to focus on a particular subject for a long period of time, without disrupting other students or having the subject embarrassed by being singled out, would be difficult and potentially unethical due to the possible disruptions to the students’ learning.

Verbal Protocol Studies
Verbal protocol studies have been undertaken to investigate the behaviours of designers. According to van Someren et al (1994) there are several methods within the area of verbal protocol studies, three of which are pertinent to this study - they are Retrospection, Introspection, and Thinking Aloud. Each uses a different processes to isolate data for the protocols.

Retrospection
Retrospection involves the subject solving a problem and then being questioned afterwards about the thought processes used during the solving of the problem. This allows the subject to give their interpretation of what happened during the design process.
Suwa et al (2000) used a retrospective protocol analysis method to study professional architects’ design sketches. Suwa et al identified behaviours, which they term Unexpected Discoveries and Situation-invention.

Retrospection has the advantage that the subject can reflect on the process without time pressure. A major drawback with retrospection, however, is that it is not always easy for the subject to remember exactly what happened, especially if some time has lapsed after completion of the task (van Someren et al 1994). In addition to this, a young subject may have no conscious idea of what thought processes were being utilised nor how the problem was solved. Furthermore, subjects may present their thought processes in a more intelligent manner than actually occurred.

Sometimes this is intentional, because people do not like to admit that they do not have the faintest idea of how to solve a problem considered as easy… Humans are just inclined to reconstruct events as more structured than they were originally. Their memory is guided by their knowledge of the result. (van Someren et al 1994, p.20).

Because retrospection occurs after the event, using this methodology requires the subject first to retrieve information from long-term memory into working memory and then to try to articulate it. The drawback is that not all the information during the actual designing task would be stored in long-term memory. This lack of storage integrity would result in the information retrieval process not retrieving all of the information that was originally in working memory whilst the design task was being undertaken. Hence some of the data would be lost. Therefore, the subject may be interpreting her/his own thought processes or even generating them anew, instead of retrieving them from long-term memory and this can be extremely problematic (Bernardini, No Date). This technique may result in invalid data because the main steps may be reconstructed while those the subject regarded as unimportant may not be retrieved; and these steps may be crucial in problem-finding.
In summary, the retrospective method, although used quite often, is not deemed to be a suitable method for data collection because it can create memory errors that could invalidate the data. It also requires the subject to interpret the cognitive processes that they have been undertaking. As mentioned also, this is a task that high school students would have much difficulty with, due to their inability to reflect on the design processes or procedures because of their lack of exposure to such methods of operation.

**Introspection**

The introspective method is similar to the retrospective method in that it requires the subject to reflect upon their own behaviour and provide explanations of their cognitive processes. However, unlike the retrospective method, introspection requires the subject to do this whilst undertaking the task. The subject has to choose when they would like to convey their thoughts. This may provide useful insights; however, these insights may not be valid data because they can easily be affected by other aspects, such as expected task performance, social pressure, and the subject’s theories of how their mind works, which are not likely to be correct (Gilmore et al 1998).

Both retrospection and introspection yield data that is easily understood. This happens because the subject is given time to rearrange their thoughts into sensible phrases. However, whilst verbalising using introspection can produce protocols that are more readable, the method interferes with the mental processes and this makes the data open to memory errors and misinterpretation (van Someren et al 1994). Furthermore, designing is a cognitively demanding task. Given this, the requirement to solve a design problem at the same time as reflect on the process could be expected to affect both the design process and the introspection adversely.
For these reasons, the introspection method was not used for this study, because the method can invalidate the data by interfering with the subject’s thoughts. Although it has the advantage of the protocols being collected in real time, the liability of data contamination was seen to outweigh any benefits gained from having readily produced protocols. In addition to this, it is argued that high school students would not have the ability to analyse and convey complex cognitive processes about which they have little or no understanding.

**Think Aloud**

The Think Aloud method asks the subject to talk aloud, while undertaking the task (Ericsson and Simon 1993). This technique encourages the subject to verbalise the thoughts that come into their mind as they undertake the task. For this study, the Think Aloud method allowed the subject to be studied in an authentic setting ie. a design workshop. In contrast to other techniques for gathering verbal protocols, the Think Aloud method does not interrupt, question or lead the subject. The subject is allowed to give a concurrent account of their thoughts while concentrating on the task at hand. This avoids interpretation and explanation of the cognitive processes by the subject. All the information is resident in working memory and in most situations is easily verbalised. As discussed by van Someren et al (1994) and Ericsson & Simon (1993), talking does not interfere with the task performance because most of the subject’s conscious effort (and verbalisations) are focussed on the task.

Concurrent verbalisation, or thinking aloud, provides data from which conclusions can be drawn regarding the cognitive processing of the individuals carrying out the tasks. Under the right circumstances (verbally encoded information, no social interaction, no
interferences, no instruction to analyse thoughts), verbalising is assumed not to interfere with the mental processes and to provide a faithful account of the mental processes occurring between them (Bernardini No Date).

In conclusion, the Think Aloud method used in this study was chosen for six main reasons, which are:

1. The Think Aloud method enables the subject to be studied in an authentic environment undertaking an everyday task – designing.

2. The Think Aloud method doesn’t require the high school students to be able to identify complex cognitive processes.

3. The Think Aloud method allows the subjects to talk naturally about what they are thinking and to focus on the task without having to be concerned about other information or be distracted from the task. This enhances the validity and accuracy of the data by eliminating interpretation and confusion between past and present behaviours.

4. The use of Think Aloud removes the opportunity for the subject to distort the information regarding the cognitive processes.

5. The Think Aloud method enables thoughts to be captured in real time and therefore no changing of ideas or reason can be made after the moment.

6. The Think Aloud method allows for the data to be collected within the 50 minute time period set by schools, in a comfortable setting with the subjects isolated from the rest of the class and with little or no distractions.

**Implementation of think aloud method for data gathering**

In order to operationalise the key questions of this research, the study aimed to immerse itself in the real world of designing in a high school context. Issues such as what types
of design problems students undertook at school and what types of design subjects they study, may have had a bearing on their problem-finding ability. The following section discusses the selection of the design task, the subjects, the setting and the collection of the data.

Selection of the design task

A design task was selected that would be regarded as authentic and meaningful to students. In addition, the task was predicted to contain sufficient complexity for students to find it challenging. This was seen as necessary to ensure students used conscious processing, rather than automatic learned responses, for which there may be no verbalisations. The design task was ill-defined and typical of the tasks that the participants were used to. The context of the design task was addressed by having the task worded in a similar manner to the usual classroom tasks, while at the same time placing them in an unfamiliar situation with an authentic industrial-based problem. The difficulty level of the task applied a small amount of pressure to perform while the authentic nature of the task motivated the students to solve the problem. The situation and design brief read as follows:

“Situation.
You are the owner of an industrial design firm and are tendering for a contract for the Brisbane City Council. Your initial designs are to be presented to the Council Board for further approval and negotiations.

Brief.
The Brisbane City Council has noted that there is a need for wheel chair bound people to have easier access to their wheelie bins. Handicapped people have complained about difficulty opening the lid of the wheelie bin and placing rubbish in it because the bins are too high for them and awkward to use. The council would like to have a solution to this problem that is affordable to the consumer and eliminates any modification to the new rubbish trucks or current operating procedures of the council.”

To try to invoke the use of problem-finding, as defined by this study, the problem was ill-defined, open ended and complex in that no modifications to the rubbish truck or current operating procedures were allowed. The design task was specifically worded to
enable it to be a type 3 problem as described in Chapter 2 by Getzels and Csikszentmihalyi (1976). That is, it was a problem that required the use of imagination as its primary cognitive function (See figure 2.1). It was the intention that this requirement may provide the opportunity for the subjects to access their higher order thinking skills. In turn it was expected that this would enable the study to obtain evidence of problem-finding as defined by this study and give some insight into its role in designing.

This study argues that, although the initial problem has been given, the problem still conforms to a type 3 problem and not to a type 2 as depicted in Dillon’s (1982) model (See figure 2.2). The reason for this is that previous literature in this area has been focused mainly in the art and mathematics disciplines and no research has been undertaken to encompass the particular characteristics of industrial designing. Industrial design problems are different because they are ill-defined, complex and require a creative response to reach a solution (Middleton 1998). Therefore, similarly to Getzels and Csikszentmihalyi’s (1976) method of art students being posed with the problem of having to arrange articles and then draw them, this study has posed that a design brief be fulfilled. Any problem-finding that is identified would have to be created by the designer as no external sources had any influence on the process. It is on this premise that the design problem is categorised as type 3. That is, because the problems, methods of solution to the problems and final solutions to them are unknown to anyone, the design task is a type 3 category.

**Participant selection**

The four subjects for this study included one volunteer student from each of the year levels 10, 11 and 12 and one volunteer high school design teacher. This group of
subjects were selected for two reasons. Firstly, there is evidence to suggest that students younger than those selected may have trouble undertaking the Think Aloud method (van Someren et al 1994). This is because they have difficulty verbalising their thoughts while concentrating on solving the design task (van Someren et al 1994). Such a situation would have led to the data not being useful due to a lack of verbalisation. Secondly, from year 10 onward, the students are exposed to design tasks that resemble the one selected for this study. They are familiar with the layout and terminology of the statements in the situation and brief. Therefore, only subjects in grade 10 or higher were invited to volunteer.

The subjects were all from the same private boys’ school. The school is a low fee paying Catholic boys’ school. The school was primarily established to cater for the poorer Catholic families in the area. Many students get their school fees subsidised by the Government or private Catholic sponsors such as the Old Boys Society. The socio-economic status of the student body is predominantly from a working class background. This is no different to the majority of other schools, be they State or Private, in the area.

The three students studied both graphics and design at school. Although they were different ages, the students had all learnt graphics and designing from the same curriculum. This is important so that some degree of control within the sample could be obtained. Variables such as having a student who had not been exposed to a design project before, or who had never done freehand sketching, or who did not understand the terminology used in designing or who had been taught design under a different curriculum at another school were eliminated.
The high school design teacher who volunteered to undertake the task was included in the study to make comparisons between the thought processes of an experienced designer and the other less experienced designers. This subject had graduated from university 5 years ago with a bachelor degree in Technology Education. This course is a design based 4-year degree which, among other things, trains high school teachers how to teach design. At the time of data collection the teacher was currently teaching design to year 11 and 12 students. In addition to this qualification and experience the teacher had 12 years experience working in the electrical trade as an electrician. During this time he was exposed to many complex design situations regarding electrical design and the installation of equipment.

The researcher undertaking this study is also a design teacher who is familiar with the Queensland Technology curriculum. The researcher works at the same school as the participants and therefore access to the subjects was made easier through personal contact with the school Principal and by having a working knowledge of the school timetable.

It is acknowledged that the researcher also being a teacher can influence the process and the results of the research, and that the nature of the relationship between the researcher and the subjects in the study may have a positive or negative effect on the outcomes of the research. For example, if the students like the researcher, it is conceivable that they may provide responses that are affected by that disposition. However, with regard to these particular students, the researcher did not teach nor has he ever taught any of them. He knew them by sight but not by name. Moreover, where there may have been some effect on the way students undertook the design task as a function of the power relationship that exists between the students and the researcher as teacher, there did not,
however, appear to be any obvious difference in how the students, engaged with the task. In addition, the researcher had access to the subjects’ prior design knowledge and this enabled easier classification of the subjects’ prior skill levels according to the Dreyfus and Dreyfus (1986) model discussed in the following section. For these reasons, while the researcher is also a teacher, which enabled easier access to the subjects, this did not reduce the authenticity of the task they undertook nor the results.

The teacher who participated in the study as a subject was a work colleague of the researcher and therefore was briefed and asked to approach the task in as normal a way as possible. The teacher was aware that with design tasks there is no right or wrong answer so it is unlikely that he would have intentionally or unintentionally responded in ways that were different to the way he would have responded without the researcher present.

Finally, neither students nor teacher were aware of the precise nature of the topic of the study. As a consequence, it is unlikely that any Hawthorne-type effect would have occurred. That is, none of the participants would have been able to define a possible preferred response and alter their natural response to conform to what they may have perceived to be the preferred response.

**Skill Level Classification**

To be able to examine any differences in design activity across these subjects it is necessary to give some indication as to the levels of skill that each of the subjects would have possessed. Therefore the five- stage classification system developed by Dreyfus and Dreyfus (1986, pp.21-36) was applied to the subjects. The five stages of skill development are called novice, advanced beginner, competent, proficient and expert.
Based on work by Middleton (1998) and by referring to the Dreyfus and Dreyfus (1986) classifications, the year 10 and 11 student was classified as advanced beginner, the year 12 student as competent and the teacher as proficient. This classification was employed to make simple comparisons across the different skill levels. The following gives a breakdown of the classifications and how they were applied to this study according to the Dreyfus and Dreyfus (1986) framework. The five stages of skill acquisition developed by Dreyfus and Dreyfus (1986) are summarised below in table 3.1

<table>
<thead>
<tr>
<th>Skill Level</th>
<th>Components</th>
<th>Perspective</th>
<th>Decision</th>
<th>Commitment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Novice</td>
<td>Context-free</td>
<td>None</td>
<td>Analytical</td>
<td>Detached</td>
</tr>
<tr>
<td>2. Advanced Beginner</td>
<td>Context-free and situational</td>
<td>None</td>
<td>Analytical</td>
<td>Detached</td>
</tr>
<tr>
<td>3. Competent</td>
<td>Context-free and situational</td>
<td>Chosen</td>
<td>Analytical</td>
<td>Detached understanding and deciding. Involved in outcome</td>
</tr>
<tr>
<td>4. Proficient</td>
<td>Context-free and situational</td>
<td>Experienced</td>
<td>Analytical</td>
<td>Involved understanding. Detached deciding</td>
</tr>
<tr>
<td>5. Expert</td>
<td>Context-free and situational</td>
<td>Experienced</td>
<td>Intuitive</td>
<td>Involved</td>
</tr>
</tbody>
</table>

Table 3.1: Five Stages of Skill Acquisition (Dreyfus & Dreyfus, 1986, p50)

There were no novice designers among the subjects used in this study. This was because all the subjects had some prior experience with designing. They had previously been educated on design principles and had applied these principles to workshop tasks.

Two of the participants Subject 1 and Subject 2 were classified as advanced beginners. From their previous design experiences (see table 3.2) the year 10 and year 11 students were considered to possess the skills appropriate to this level. The reason for this is that, in addition to being able to apply design principles in context-free tasks, as is required of a novice, these subjects had been exposed to contextual features of problems also. It is the ability to apply the design principles that they have learnt to unfamiliar situations, such as the design task in this study, which makes these two advanced beginners.
The year 12 subject (Subject 3) was classified as being competent because he had been exposed to a much wider variety of contexts than the other students. He had studied Senior Graphics and Engineering Technology (both design-oriented subjects) for one year longer than the other students. These two subject areas required the student to work at progressively higher levels as he moved through his studies. In so doing, the student was taught to identify complex problems and to break them down into smaller problems and make decisions about the outcomes. Through studying these subjects and being near the end of his course of study, this subject was considered to possess the skill level required for being considered competent.

The electrical tradesman/design teacher (Subject 4) was considered to be proficient. Proficiency is achieved when one has considerable experience in an area. For this subject this included his experience working in a trade, which consistently exposed him to high level electrical problems. To solve such problems he had to have an understanding of electrical trade practices as well as a good knowledge of electrical fundamentals. This would have enabled him to make judgements about how to complete a task or solve a problem in the most efficient manner. In addition to his electrical background, this subject had completed a University degree as a high school design teacher and had been teaching for 5 years. The reason for this subject being classified as proficient and not expert was the lack of experience in the industrial designing domain, the area of design that this study is focussed on. He would still use his experience in teaching design but would use controlled analysis to solve the design tasks instead of automated processes as is required for expertise.

Although this study did not use any experts, an expert is one who has extensive knowledge and has the ability to apply that knowledge to a particular domain. Experts
rarely rely on controlled cognition. They tend to use rules of thumb or they do what has worked for them in the past (Dreyfus & Dreyfus 1986). To clarify the status of the four subjects further a profile of them is given below in Table 3.2.

<table>
<thead>
<tr>
<th>Subject identifier</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
<th>Subject 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>31</td>
</tr>
<tr>
<td>Sex</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>School Grade</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>N/A</td>
</tr>
<tr>
<td>Drawing Experience</td>
<td>2 years Junior Graphics.</td>
<td>3 years Senior Graphics and 0.5 years Senior Graphics</td>
<td>3 years of Junior Graphics and 1.5 years of Senior Graphics</td>
<td>9 years in trade, 4 years in University and 5 years teaching</td>
</tr>
<tr>
<td>Design Experience</td>
<td>2 years of Design and Technology.</td>
<td>3 years of Design Technology and 0.5 years of Technology Studies</td>
<td>3 years of Design Technology &amp; 1.5 years of Engineering Technology</td>
<td>9 years in trade, 4 years in University and 5 years teaching</td>
</tr>
<tr>
<td>Level of expertise</td>
<td>Advanced Beginner</td>
<td>Advanced Beginner</td>
<td>Competent</td>
<td>Proficient</td>
</tr>
</tbody>
</table>

Table 3.2: Profile of subjects studied

The study reported in this thesis is concerned with the aspect of designing defined in this dissertation as problem finding. The approach taken is from cognitive psychology. In that sense the study is attempting to understand the thinking processes associated with problem finding in design. It is acknowledged, however, that the act of problem finding, and indeed the process of designing, does not occur in isolation from the setting in which the designing takes place and the historical and social background of the participants in the study. As a result, it is reasonable to assume that many of the choices participants made during the design activity they engaged in were the result of social or cultural factors, as well as cognitive factors. Thus a student from a rural background may make different decisions to that of a city student. Similarly, all participants will probably approach the design problem in ways that they would see as acceptable within their interpretation of the social mores of the setting which in the case of this study is a Catholic boys school.

The socio-cultural aspects of designing have become an important area for research with studies by Sivaloganthan et al (2000) and Stempfle and Badke-Schaub (2002) being two
examples. Sivaloganthan et al and Stempfle and Badke-Schaub examined the socio-cultural aspects of group work with a focus on how people interact regarding the function, behaviour and structure of the design product. Others (Dong 2004) have examined the level of awareness among team members of how others interpret the function, behaviour and structure of the artefact and the similarities and differences among their interpretations. Thus studies in the socio-cultural aspects of designing help to illuminate the socio-cultural content of designing.

This study is seen as complementary to studies of designing from a socio-cultural perspective in that it seeks to illuminate cognitive aspects of the process of designing in particular settings. This study thus provides the basis for future research into the relationship between cognitive and socio-cultural aspects of designing.

**Selection of the setting**

The setting for undertaking the design task was a regular school workshop, of the kind used for design classes. However, the tasks were undertaken at a different time to the regular class to facilitate data collection. Special permission was sought to have the subjects undertake the task when the workshop was not being used. The workbench where the task was undertaken was an appropriate height for the subjects to stand and work at, or, if they chose to, sit on a stool that was provided. Each of the 4 subjects had the same set of materials positioned in the same place. These included: 10 sheets of A3 paper, 2 pencils, 2 white board markers, 2 felt pens and a wheelie bin. A digital video camera was positioned above their head and slightly towards the top of the paper so the subject could not be identified and the best position to capture the sketching unobtrusively was obtained. Four small pen marks were placed on the workbench and subjects were instructed to try to keep the paper inside these marks so that the video
camera would always be focused on the paper. A unidirectional microphone was positioned overhead and out of view to capture the verbalisation clearly. Both the video camera and microphone were operated by a discrete remote control held by the researcher who was positioned slightly away from, and to the left of the subjects.

A wheelie bin was situated beside the subjects to allow them to have a stimulus object and context for their design task. The wheelie bin was the type with which all the subjects were familiar because it was one of the bins used in the school workshops.

**Collection of the data**

The subjects were given the task of designing a device to enable a wheel chair bound person to have easier access to their ‘wheelie type’ garbage bin without requiring modifications to existing garbage trucks. None of the subjects was aware that the other subjects were undertaking the task. Each undertook the task individually with only themselves and the researcher present in the room. Each subject was given the same instructions and separately video and audiotaped as they attempted to solve the problem. Before the commencement of the main design task, a ‘warm up’ session was conducted. This was a five-minute session that helped the subjects understand what was required when undertaking the Think Aloud procedure. van Someren et al, (1994) suggests that a ‘warm up’ session not only allows the subject to become familiar with the thinking aloud process, but also gives the experimenter an opportunity to train the subject to verbalise their thoughts and not to interpret their thoughts. Based on this recommendation, the subjects were each given a simple 3 peg Tower of Hanoi puzzle (Anderson 1993) to solve while they verbalised their thoughts. This short session enabled any questions about the technique to be answered. All subjects were able to use the technique acceptably well. After 5 minutes, the subjects were told they were about...
to undertake the main task. The instructions for the main task were given to them on a sheet of paper with the design task attached to the bottom. The subjects were instructed to keep the sketching paper inside the marks on the table. No conversation happened after this time. The video and audio-tapes were started at this point. The instructions read as follows:

**Instructions**

You are about to undertake a design task in which your actions and voice will be recorded. During the designing phase you are asked to sketch your ideas and to talk about what it is you are thinking or doing throughout the design process. If you stop talking for more than 10 seconds, I will prompt you by asking you what you are thinking.

**PLEASE NOTE:**
Please don’t ask me to help you or to make the situation or brief clearer as I can not. I will not enter into any conversation or answer any questions about the designing process, you are on your own. I am simply here as an observer and to prompt you to communicate aloud when you forget to.

There is no time limit on the task.

There is plenty of A3 paper supplied and an assortment of drawing instruments.

I have supplied a wheelie bin that may help you with the task.

If you find difficulty with the Situation or Brief you may use your own judgement as to the best way to solve the problem.

Once again please don’t ask me to help you or to make the Situation or Brief clearer as I can not help you.

After the design task had been completed the video/audio tape and sketches were collected for analysis.

**Preparation of data for analysis**

The verbalised data was digitised, transcribed and segmented into meaningful segments as described below. The visual data was used to clarify any intentions or meanings not evident from the verbal data.
Segmentation of the transcripts

The segmentation of the transcripts used a similar method to that of Suwa et al (2000), who divided the protocol based on a shift of intention by the subject, of details, of thoughts or actions. This method has been used by others such as van Someren et al (1994), Gero & McNeil (1998) and Middleton (1998). The process meant that some of the segments were small and relatively meaningless. Ericsson & Simon (1993) noted that research in language production and language understanding showed that in speech the boundaries of phrases are usually marked by pauses. The combination of these pauses and the linguistic structure provide a natural and general method to segment a think-aloud protocol. To enable some protocols to make sense, on occasion it was necessary to combine the segments together, working from a small segment up to a longer, more understandable one. Past experience with segmenting protocols has shown that there is a high level of agreement between people asked to segment a written protocol while listening to the verbalisation (van Someren et al 1994). Thus the study used an accepted conventional method for the segmentation of the transcripts.

Coding the data

The data underwent two stages of coding. In the first stage the data was coded at a macro level. That is, a general overview of the segments was undertaken in terms of identifying problem-finding episodes. In the second stage the data was subjected to micro level coding. This involved a more refined and closer look at the data in terms of the problem-finding categories.

Coding at the macro level consisted of placing the segments in a spreadsheet consisting of two columns. The first column contained a segment number used to identify each segment, and the second column contained the segment. An initial coding system was
used to sort the data at a macro level. This process enabled the study to refine the data by identifying the problem-finding episodes and to eliminate any data that was deemed to be of no use to the study. The macro-code was used to identify any problem-finding incidences according to the description of problem-finding given in Chapter 1, which was: problem-finding is both the detection of difficulties and also the finding of new questions for scrutiny. While reading through the segmented transcripts, the coders underlined any segments they felt matched this description of problem-finding. At times a single segment did not provide sufficient detail to justify being classed as problem-finding because it made no sense when taken out of context. On these occasions it was necessary to group segments together as episodes. The segment that best described problem-finding within the episode was the segment that was marked as problem-finding. A sample of the initial protocols is given in figure 3.1.

74. Just what I’m going to draw.
75. Umm the size of the pedal has to allow it to open up enough.
76. I could put a top view there of the handle
77. top of the lid
78. its got a handle there
79. and you could rope it around the handles at the back
80. I’d say about 70 m of rope
81. tie it there and to there and then at the bottom
82. I’ve gotta have enough room so that the pedal doesn’t hit dig into the ground
83. so you’ve got to put it up high enough for that
84. umm I’m sort of thinking what angle to put it on as well
85. so they can push it easy without moving the bin or making it fall over or anything
86. If I make it 45 degrees up to the right of the bin
87. and that way they should be able to push on it

Figure 3.1: Sample of macro coding

The highlighted lines in figure 3.1 were deemed to be problem-finding episodes because they either formed an obstacle (as in line 84) or they enabled the subject to want to move on with the design (as in lines 75 and 82). Most of the protocols at this stage were meaningless on their own therefore to enable a valid method of microscopically coding the protocols, they were first re-coded in context by reading the segmented transcripts
and, if required, looking at the video/audio tape. This allowed the coders to gain a clearer understanding of the context of the segment.

The data was then coded at a micro level using only the segments that were identified in the macro examination and consequently categorised as problem-finding. The new coding scheme for a micro examination was derived from theoretical models (Yashin-Shaw, 2001, and Finke, Ward and Smith 1992) and also derived from the protocols and then applied to the data. The coding scheme contained four categories comprising:

1. **Clarification** (Protocol derived): This is where a designer clarifies the initial given problem to be solved by finding problems that need answers. The clarification must refer back to the original problem. e.g. “Allright well this bin the council already supplied, it’s obviously too high for a wheel chair person to open so I need to obviously make the lid smaller”. The implied sub-problem here, is that the bin is too high for a wheel chair person to open.

2. **Elimination** (Yashin-Shaw 2001): This is where the designer eliminates a solution for a problem by finding a problem that makes the proposed solution unusable. e.g. “Oh this isn’t going to be able to lift the lid I don’t think”. The implied problem found here is that the designer has found a problem with the solution he has been working on previously. It is a self-regulating process.

3. **Exploring ideas** (Fink, Ward and Smith, 1992): This is where the designer adds to the solution by finding a problem with the current solution. e.g. “but before you pull the rope a pin has to go in here somehow”. As they are designing, they find a problem with a part of their solution and use this to build and refine their idea.

4. **Lack of Knowledge** (Protocol derived): This is where one is unable to solve the problem through a lack of technical knowledge. The problem found here is that the designer doesn’t know how to solve the problem because they can not find a
solution. e.g. “but I just don’t know how to get it to work”. In essence the designer has found a problem because they don’t know how to progress any further with their design.

The new coding scheme enabled a micro examination of the data. The coders had to identify which of the four categories each segment belonged to. This information was then placed on a spreadsheet. A sample is included as Table 3.3.

<table>
<thead>
<tr>
<th>Segment identifier</th>
<th>Segment</th>
<th>Coding category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Clarification</td>
</tr>
<tr>
<td>42</td>
<td>So once it gets to the top it’s got to somehow be able to tip</td>
<td>✓</td>
</tr>
<tr>
<td>47</td>
<td>oh this isn’t going to be able to lift the lid I don’t think…</td>
<td>✓</td>
</tr>
<tr>
<td>53</td>
<td>there’s something that’s got to come up and lift the handle before this reaches the top for that to tip down</td>
<td>✓</td>
</tr>
<tr>
<td>55, 56</td>
<td>ahh it couldn’t be actually because then the truck couldn’t pick it up</td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 3 3: Sample of micro coding

Data analysis method

The method employed to analyse the data consisted of two qualitative stages. The first stage addressed Key Question No 1 and the second stage Key Question No 2. Each is discussed separately in the following sections.
Data Analysis Stage 1

The first stage of the data analysis was focused on answering Key Question No 1 which is ‘When does problem-finding occur within the problem-solving process?’ To answer this question there was a need to gauge firstly if problem-finding did occur throughout the design process and secondly how often and where it occurred. The approach taken was to analyse the protocols of each subject by comparing the frequency that problem-finding occurred with the time that it occurred. This was aimed at establishing a pattern to show how often and when problem-finding happened for each subject. A sample in figure 3.2 is presented below.

![Figure 3.2: Frequency of problem-finding by time quartile for subject No. 3](image)

The number of problem-finding episodes, represented as rows in figure 3.2 was the result of the macro level coding: that is, the number of times a subject used problem-finding to solve the design task. This is graphed against the total time each subject took to complete the task. The total time was divided into quartiles so that a comparison could be made across the subjects. That is, although each subject took different times to solve the problem, the quartiles represented exactly the same relative proportion of the problem-solving task duration. In this way, the results between the subjects would be
compared in terms of whether or not problem-finding did happen throughout the design process and not simply at the beginning as discussed in Chapter 2.

The findings of the analysis for Key Question No.1 are presented in Chapter 4, where it is established that problem-finding did occur throughout the problem-solving process as hypothesised throughout this study.

**Data Analysis Stage 2**

Stage 2 of the analysis followed from the findings of the first stage. It built on the notion of problem-finding by analysing the data in a more fine-grained style. The second stage is focussed on answering Key Question No. 2 ‘**What types of problem-finding occur in design and what roles do they play?**’ Part of this question has been answered by the identification of four problem-finding categories: Clarification, Elimination, Exploring Ideas, and Lack of Knowledge, as derived from the data during the micro level coding. However, to enable a comprehensive understanding of the types of problem-finding, Key Question No. 2 requires an analysis at two levels: Firstly, analysing the relationship between the categories of problem-finding and when they were used during the design task, and secondly, analysing the relationship between the type of problem-finding category used and the level of expertise in design of the subject solving the problem.

The first level of analysis graphed the frequency of each category against the quartile in which it was used. This analysed how often and when a category was used and allowed for patterns between categories to be identified to examine if there were different types of problem-finding. A sample is given in figure 3.3.
In Figure 3.3 it can be seen that the problem-finding category of Clarification was evident only in the first quartile of the problem-solving process. After the first quartile there were no more episodes of Clarification for this subject.

The second level of analysis compared the problem-finding categories, frequency of problem-finding and expertise of the designers. The discussion at this level was used to explore the ways in which the design experiences of the subjects related to their problem-finding ability.

**Strengths and limitations of the study**

The strengths and limitations of scientific studies focus around the issues of reliability and validity. Reliability deals with an indicator’s dependability to produce the same result each time the same thing is measured, while validity reveals whether the measurement is actually capturing the meaning of what is claimed to be measured.
(Neuman 1994). The strengths and limitations of this study are addressed through discussion of reliability and validity.

**Internal Reliability**

Internal reliability is the yardstick which measures the ability of the design of the study to enable other researchers to achieve the same results. For this study internal reliability was gauged through a special type of equivalence reliability called Inter-coder Reliability (Neuman 1994).

**Inter-coder reliability**

Measures of inter-coder reliability were undertaken to ensure that the coding was applied consistently throughout the study and that the element of chance was minimised. The study used two independent coders to code the data. Each coder had no interest in the study and undertook the coding at the same time but in different locations. Together, both coders were given minimal information about the study and were asked to be as precise as possible. This prevented the researcher giving different information to each of the coders. The coders were then asked to go to separate rooms to conduct the coding sessions. Because the data was coded twice there were two checks on inter-coder reliability. The first check was done at the macro level and the second at the micro level.

**Macro level inter-coder reliability**

The macro level coding was a measure of the reliability of the two coders to identify problem-finding segments from the data. This measurement produced an average coder correspondence of 96.25%. The Kappa measurement (van Someran et al 1994, p.131), which has been used in verbal protocol studies to measure differences in marginal frequencies of coders, was also applied. At the macro level the average Kappa was 0.808. The suggested acceptable Kappa is 0.70 or above (van Someren et al 1994,
Due to the Kappa score being higher than the recommended minimal score, the coding at the macro level was accepted as being reliable.

Because the segment numbers were relatively small (less than 70), the nature of the data analysis meant that 100% accuracy in coding must be obtained. To achieve this, the segments where there was disagreement were identified, and the coders proceeded to discuss the issues around the segments until agreement was reached. At times the video/audio tapes were used to clarify any meaning lost due to the removal of context.

**Micro level inter-coder reliability**

The second check for inter-coder reliability was performed at the micro level. This measured the reliability of the coders to categorise the problem-finding segments identified at the macro level into four categories at the micro level. The average coder agreement at the micro level was measured to be 84.75%. The average Kamma measurement was 0.692.

The Kappa was slightly less than the recommended 0.70. However, due to the nature of the design task, the small number of segments coded and the closeness to the recommended Kappa level it was considered that an acceptable level of reliability for the micro-level was achieved.

The segments that were not agreed on by the coders were discussed and where necessary the audio and videotapes were used to clarify the context. As was the case with the macro examination, the micro examination required 100% agreement between the coders. It was found that most of the initial disagreements between the coders were
the result of ambiguities in the context of the segments. The results of the discussion enabled 100% agreement of the coding to be achieved.

The reliability levels that were achieved and the steps that were undertaken to ensure inter-coder reliability were of a sufficient standard to conclude that the study did not involve any subjective judgements by the coders. Hence it was concluded that the reliability of the study was of an acceptable standard for a study of this type.

**External Reliability**

External reliability is the extent to which the results of the study may be reproduced by an independent researcher studying the same phenomena under similar conditions. This study was not designed to be duplicated in an experimental way and therefore the extent of external reliability applying to this study is minimal. Although it is difficult to reproduce qualitative studies, the external reliability of this study was addressed by ensuring that an accurate description of the setting, subjects, instruments used, procedures and methods were provided. This will enable other researchers to conduct similar studies in this area.

**Internal Validity**

Internal validity means that there are no errors internal to the design of the study (Neuman, 1994). Although the Think Aloud method does not suffer from the hazards of disturbance, memory errors and interpretation as much as other techniques do, there are, according to van Someren et al (1994), two new threats which can affect the validity of the data. They are: incompleteness due to synchronisation problems and invalidity due to problems with working memory. None of these are considered to diminish the
credibility of the study due to the precautions undertaken by this study as discussed below.

Incompleteness due to synchronisation problems can occur when cognition is undertaken at the same time as verbalisation. The cognitive processing takes longer than it would if there were no verbalising. At times, the verbalisation may not keep up with the cognition and this can result in a report that is incomplete and may contain holes. The subject may be concentrating so hard on a particular task that they forget to verbalise their thoughts. For these reasons the synchronisation between their thoughts and their verbalisation can be lost (van Someren et al 1994). To reduce this problem the study has incorporated both verbal and visual methods of collecting the data. The advantage of this combination is that, if the subject is not verbalising, they may still be sketching their ideas. Therefore even though they are not verbalising their thoughts, the data can still be captured through the sketching and video-taping. This method limits the problem of synchronisation by allowing the sketching to replace the verbalisation and so doing keep up with the cognition. In these instances the visual data becomes the primary source of data rather than the verbalisation. Both, the sketches and the verbalisations were used to collect and analyse the data.

Invalidity due to problems with working memory occurs when the information is complicated and non-verbal as in a sketch or a visual image. This extra cognition takes up space in working memory and, as a consequence, takes more time to reason the information. This can disrupt the process and cause the protocols to be incomplete. To reduce the effects of these threats a technique called prompting can be incorporated into the study once the subject has stopped talking. Therefore, this study included prompting into the methodology, which allowed the researcher to speak to the subject and say,
“Keep on talking”. According to van Someren et al (1994) this is usually enough to keep the subject thinking aloud.

In summary, the Think Aloud method does have two potential limitations due to synchronisation and working memory problems. Firstly, this study has addressed the issue of synchronisation problems by using a dual method to collect both visual and verbal data. Both forms of data were used in the study. Secondly, possible problems associated with working memory are addressed through prompting. This study has ensured the methods used to collect the data are valid because of the safeguards put in to place to reduce any potential hazards.

**External Validity**

External validity addresses the question of: “If something happens in a laboratory or among a particular group of subjects, can the findings be generalised to the ‘real’ world or to the general public.” (Neuman 1994, P.136). External validity can never be generalised with certainty. It is always a question of more or less similarity. The validity of a study is about different generalisability contexts and developing a theory about which contexts are more like the study and which are less so (Trochim, 2002).

To address external validity there are four main components that need to be considered. They are: people, places, time and settings: Can the research, which was done in a specific place, with certain types of people, and at a specific time be generalised to another context (Trochim, 2002)? The following discusses each of the components of people, places, time and settings with regard to increasing the level of external validity in this study.
**People**

To what degree the sample used in the study is representative of the general population or of other similar populations (design teachers and design students) is difficult to ascertain. The study makes no claims regarding the generalisation of the people in the study. That is, the intention of the study was to examine in depth, the thought processes of a limited number of subjects undertaking a design task. However, there is no evidence to suggest that the sample was systematically different to other design teachers or design students. Because the people in this study were not selected but were all volunteers, there would be no reason to suspect that the sample is in some way different to other high school design students undertaking the design subject.

If the study had been conducted with girls rather than boys there may be some differences in the way that girls and boys design. That is, girls may not view the problem as one that requires a technical solution but maybe a more organisational or social solution. Girls also tend to work in-groups when solving design problems.

Like wise, if the study had been conducted with subjects that had a different cultural background than the people used in this study, there may have been differences in their attitudes, language and aspirations. Therefore, there may be limitations about the generalisability of the findings across different cultural and gender groups. However, as noted earlier, that was not the intention of the study. The study was examining the thinking process of problem-finding of individuals and although the topics and solutions to the problem may be different among girls or boys and different cultures, the types of problem-finding and the way in which they are employed may be broadly similar.
Places and Time

External validity regarding places and time tries to answer the question of; if this study were conducted in a different place and at a different time would the results be the same? This study is endeavouring to capture the thinking processes of several subjects undertaking a design task. In Queensland, school is a place where most high school students studying design would undertake such tasks. As such there is no evidence to suggest that if the volunteer subjects undertook the task in a different school located at a different place or at a different time that there would be any change in the results. The nature of designing and the way it is taught in Queensland means that it can be performed in many places and at any time. Therefore, the population of Queensland high school design students, for which this study is interested in making conclusions about, would be minimally affected by a change in place and time. The study recognises that the subjects attend a private boys’ school but, the socia-economic status of the clientele and the environment of the school are no different to other working class schools in the area.

Setting

The setting of the study is important to the external validity of the study. The setting includes four areas: the surroundings, the atmosphere, the language used in the design task, and the type of task undertaken. The data collection for this study was undertaken in a real high school design workshop. Most designing in Queensland high schools occurs in workshops similar to the setting used in this study.

The first area of concern is the surroundings of the subjects. Because an actual design workshop was used, the surroundings of the subjects were no different to what they are used to. The workshop had benches, stools, tools and machinery as would be expected
of a design classroom. The wheelie bin used as a stimulus for the design task was the actual bin from the workshop. The presence of the video camera may have had some effect on the subjects. However, to reduce the effect, the video camera and microphone position were trialed and changed so that they were in a non-intrusive position out of view of the subjects.

The second area of concern is the atmosphere of the workshop. The atmosphere of the design workshop may have had an effect on the subjects because it was necessary to have each subject undertaking the design task alone (except for the experimenter). This meant that the atmosphere of a usually noisy workshop was not present. There were, however, design classes being undertaken in the workshop next door and the familiar sounds of children talking, music on the radio and machines operating. These were all easily heard by the subjects and added authenticity to the atmosphere of the study. This meant that although the study did not reproduce the usual atmosphere contained in a workshop, the atmosphere closely resembled that which the subjects would be used to working in, and in fact had worked in before.

Because the subjects were not allowed to interact with their peers to discuss design issues as they usually would do, there may have been some effect on the subjects’ performance. However, the need to have a reasonably quiet setting with little distraction to enable the verbalisations to be captured was a necessity of the study. It is possible that having the subjects undertake the design task alone may have minimally affected the results of the study. However, the need to capture clear verbalisations was regarded as necessary to the design of the study and therefore the subjects undertook the design task alone. While the atmosphere of the setting may have affected the results of the study, the threat to the validity of the study was regarded as not being serious.
The third area of concern is the language used in the design task. The wording of the design task was closely examined to make sure that it reflected similar wording to other tasks that are undertaken by high school design students. The task included a situation and brief, terms that are commonly used in design subjects undertaken at high school from grade eight onwards. The language used was reflective of the culture of most Queensland high school students. The use of terms such as ‘wheelie bin’ is typical of the language that most students living in Queensland would be familiar with.

The final concern is the type of design task undertaken. The task was chosen because it made the setting more realistic by placing an emphasis on real local design issues. When combined, a problem dealing with rubbish removal, wheelie bins and handicapped people are issues that high school students may find interesting to solve. The task was simple enough to enable the subjects to understand the problem clearly while at the same time complex enough to require considerable attention from the subjects. Because the task was not essentially different in kind to other design tasks the subjects had been given as part of their normal school curriculum, the task was seen as not posing any threat to the external validity of the study.

In summary, the strengths and limitations of the study can be summarised as follows.

Strengths.

- The study used two independent coders to code the data.
- The study used statistical measurements to check for inter-coder reliability.
- The study used both audio and visual data to provide a rich data source to overcome problems associated with the interpretation of the context.
The use of verbal and visual data provided a source for triangulation for data analysis.

The data analysis was of a small sample but to a great depth.

The study provided accurate descriptions of the setting, subjects, instruments and methods used.

The people, activities and setting where the data was collected represented a high level of authenticity in terms of their resemblance to the activities they were intended to research.

Limitations:

- The number of subjects studied was small, and therefore generalisability is limited.
- The subjects were all male and therefore limited comparisons can be made between possible results due to gender differences.
- The subjects were all from a similar cultural background and therefore limited assumptions can be made regarding the generalisations of the study. For example, a different cultural specific Design Brief would have to be employed for aboriginal students from an outback school who may not have seen a Wheelie bin.
- Some data may have been lost due to synchronisation problems between verbalisation and cognition.
- Some data may have been lost because of the extra cognitive demands required when sketching.
- Although the codings of the data showed a high level of congruence between the coders, a 100% agreement was not achieved without some consultation.

None of these limitations were seen as posing a threat to the validity of the study.

However, it is not claimed that the findings can be generalised across all students or all
classes in schools. Rather the study seeks to illuminate the kinds of problem-finding that this set of students actually used and to examine the theoretical implications.

**Conclusion**

This chapter operationalised problem-finding in this study by arguing that problem-finding may be studied by analysing the thinking processes of people solving a design task. It was further argued that the Think Aloud method was the most useful method to use. The reason for this was that, under the right circumstances, the Think Aloud method can reveal thinking processes through verbalising in real time, in an authentic setting and in the 50 minute time constraints of high school lessons. The verbalising can then be recorded and used as rich data to draw conclusions about the students’ cognitive processes. In addition, the Think Aloud method was deemed suitable for high school students because they were not required to have an understanding of complex cognitive processes as is required of other methods.

It is also argued that the strength of the research design lies in its ability to analyse the data at both a macroscopic and microscopic level. This in-depth analysis allows the data to provide the basis for valid findings and provide a very detailed insight into the problem-finding capabilities of several individuals. The method for capturing, coding and analysing the data is described along with profiles of the subject’s experiences and details of the task and setting are given.

The following chapter presents the results and analysis of the study.
Chapter 4: Results and Analysis

Introduction

This study used a qualitative subject-study approach to explore the role of problem-finding in designing at the high school level. Four subjects were videotaped while undertaking a design task using the Think Aloud method as described in Chapter 3. The problem-finding episodes were identified and categorised using the videotape and transcripts. It was argued in Chapter 2, on the basis of existing research literature, that problem-finding should occur not only at the beginning of problem-solving but throughout the whole problem-solving process. It was also argued that problem-finding presents itself in different forms. That is, in addition to problem-finding being seen as an act of detecting difficulty, it can also be seen to create a desirable situation by raising new questions for inquiry. In the following sections the data is represented and analysed in relation to the particular design problem presented. The results and analysis are in two sections. The first section addresses Key Question No. 1, which is: When does problem-finding occur within the design problem-solving process? The second section addresses Key Question No. 2, which is: What types of problem-finding occur in design and what roles do they play?

Occurrence of problem-finding in problem-solving

To analyse Key Question No 1 this section is organised in two parts. Firstly, a comparison between the number of problem-finding episodes for the four subjects is discussed. Secondly, a comparison of how problem-finding was used over time by the subjects is presented.
Comparison of frequency of problem-finding between subjects.

Results

Figure 4.1: Graph of the total number of problem-finding episodes

This section compares the frequency of problem-finding episodes across the 4 subjects. Figure 4.1 shows a graph of the relative distribution of problem-finding from the youngest and least experienced (S1) to the oldest and most experienced (S4). There were a total of 67 episodes of problem-finding identified. In its simplest form the graph shows that all four subjects used problem-finding to solve the design task, Subject number 1 (S1) was the youngest (15 years old) and least experienced (Grade 10) of the subjects. Classified as an advanced beginner (Dreyfus and Dreyfus 1986), S1 found the fewest problems (N = 8). Subject number 2 (S2) was 16 years old, in grade 11 and classified as an advanced beginner (Dreyfus and Dreyfus 1986). The number of problems identified by S2 was N = 17. Subject number 3 (S3) was the most experienced of the student subjects. At 17 years old and in grade 12 he was classified as competent (Dreyfus and Dreyfus 1986). The number of problems identified by S3 was N = 30. Subject number 4 (S4) was the 31-year-old design teacher. He was classified as being a proficient designer (Dreyfus and Dreyfus 1986). The number of problem-finding episodes identified by S4 was N = 12.
Analysis

For the students, the graph shows an almost doubling of the number of problem-finding episodes for every yearly age increase. This may indicate that as the student’s age and experience increases, they may be more capable of using problem-finding to solve a design problem. Cross (2004) discusses the transition from novice to expert, and concludes that one aspect of expertise is that it is the result of dedicated application in the field. According to Ericsson and Simon (1993), this usually takes about ten years from the time of first involvement.

Subject 1 found the smallest number of problems while Subject 3 found the largest number. This could be due to differences in age between the two subjects. However, subject 4 (the eldest and most experienced) found a considerably smaller number of problem-finding episodes than subject 3. This result casts some doubt on the suggestion that the older and more experienced a person was the more they tended to engage in problem-finding. An alternative reason for the decline in problem-finding episodes for S4 may be that the more experienced designer is different in some way to the others. For instance, S4 may have been finding fewer, but larger problems, due to differences in the underpinning knowledge and experience of the subject. According to Patel and Ramoni (1997) the more experience a person has, the better is their ability to organise their knowledge hierarchically. This ability allows them to pick out what is relevant and ignore what is irrelevant. This could mean that the experienced designer may not have verbalised the irrelevant problems, but recognised them in their mind and immediately moved to an alternate solution automatically. That is, the problems were still there, but the experienced designer’s use of heuristics (rules of thumb) or automatic procedures may have enabled him to bypass them instantaneously without verbalising them.
Consequently, they may not have been identified in the data. S1 and S4 had a similar number of problem-finding episodes. This may seem unusual, as one is quite an inexperienced designer while the other is a proficient designer. The following presents an explanation for these results.

The similarity in the relatively small number of problem-finding episodes (as compared to S2 and S3) of S1 and S4 could have been interpreted as indicating that there were similarities between the two in terms of their problem-finding ability. This is not necessarily so. Rather, an explanation for this may be found in the way that they solved the problem and the type of knowledge that each possesses. Experts and novices solve problems differently (Casakin, & Goldschmidt, 1999). The finding that novices may represent problems or task situations in terms of irrelevant features that do not lead to a correct solution, while experts tend to focus on more profound features, is well documented in the problem-solving literature (Anderson, 1990, Newell, & Simon, 1972). As expertise develops, knowledge becomes more structured and better integrated with past experiences, so that it can be retrieved from memory in larger chunks. That is, the more experienced a person is the more semantically rich (Robertson, 2001) the knowledge the person would have about solving a problem.

According to Anderson, (1993) the younger, less experienced subject would tend to use more declarative knowledge (ie. knowledge that) than procedural knowledge (ie. knowledge how). S1, being less experienced than S4, would rely mainly on declarative knowledge to find a problem and then verbalise the problem. The problem would be identified and verbalised because it would seem difficult to him as he hasn’t been exposed to similar problems or experiences before and hence wouldn’t possess the procedural knowledge to help solve that particular problem. Because of his limited prior
knowledge he would be able to look at the problem only at a shallow level. That is, he would approach the problem as if it were semantically lean (Robertson 2001). Therefore, he would only verbalise a limited number of problem-finding episodes. Novices don’t know what is relevant and therefore tend to stay with the surface features of situations (Patel & Ramoni, 1997).

Alternatively, when the more experienced S4 identifies a simple problem he would sub-consciously and automatically solve it using his embedded knowledge. This would leave him free to concentrate on the more difficult aspects of the problem. Therefore, although S4 may have come across many problems, he may not have verbalised them all because he solved many of them automatically. This is because he has a store of procedural knowledge from which he can draw answers to a problem quickly. A problem that S4 deems as being semantically rich may seem semantically lean to S1. Thus while the interpretation of the graph shows similarities between the two subjects in terms of the quantity of problem-finding incidents, the graph does not account for any non-verbalised problem-finding which may be the result of the subjects’ ability to apply heuristics to identify problems.

It is concluded that while S1 and S4 engaged in a similar number of problem-finding episodes to solve the problem, the cognitive processes being used by each subject were different, this is supported by examining the transcripts themselves. The verbalised problem-finding episodes were comparable to the experience of the person being studied.

Again, looking at graph 4.1, a similarity between the subjects S2 and S3 is evident. Both are in the higher range of problem-finding episodes, as compared to S1 and S4. This is
interpreted as indicating a relationship with their prior experience. Both subjects had spent similar time and been exposed to similar design experiences at the school level. S2 did have one year less exposure to designing than S3, and this is reflected in the data through a reduced number of problem-finding episodes (17 compared to 30). Patel and Groen (1991) suggest that intermediates (advanced beginners and competent practitioners) have a lot of knowledge but that knowledge is not yet well organised. This lack of organisation makes it difficult for them to encode information from working memory and to access information from long-term memory. Therefore, the reason that S2 and S3 used problem-finding more than the others may lie in the fact that they were trying to process a large amount of knowledge but as yet were unable to do so. They would have wanted to take the context of the problem into consideration but generally fail when they tried to do so. For example, an extract, presented below, from the transcript of S3 highlights the type of cognitive load that these subjects encountered.

'\[quote\]see, you can’t have something that clamps to the bin because that would be lifted when the garbage truck comes…and we can't really alter the height of the bin either because then the truck wouldn’t be able to pick it up as easy see at the moment I’m still thinking of something that could lift the rubbish up and drop it in somehow probably not from this angle because the bins going to open up this way so it won’t be able to get over there so possibly something from the side.\[/quote\]

This indicates that he was trying to process a lot of knowledge at one time. Instead of breaking the problem down into smaller chunks, he tried to solve the problem by considering all the constraints placed on the design at once. This led to his having to use a trial and error method of finding problems to ensure his design would work. As a result he tended to verbalise many problem-finding episodes because he was trying to process knowledge that was both relevant and irrelevant to the design.
In summary, the results suggest that at some point in their cognitive development a person’s past design experience may begin to have an effect on problem-finding ability. That is, a problem may change from being semantically lean to semantically rich depending on the person’s past experiences. The findings of this study are interpreted as indicating that these students tended to use more problem-finding episodes as a function of experience. That is, the use of problem-finding increased the more experienced they became until, at an unknown point, the frequency of verbalised problem-finding began to decrease as problem-finding became more automatic.

A second question is when problem-finding is used during the problem-solving process. Current research discusses problem identification only at the beginning of the solving process and not at various times throughout the solving process. To help answer this question, the problem-finding episodes were graphed over time and analysed.

**Comparison of problem-finding over time divided into quartiles**

After ascertaining that all subjects used some form of problem-finding and that there was a difference in the number of problems that were found between the four subjects, a closer look at the data was undertaken. To enable the data to be represented in a meaningful way, the number of problem-finding episodes verbalised was plotted against the total time each subject took to complete the design task. The total time was divided into quartiles so that a better comparative analysis could be made across the subjects. That is, although each subject took different times to solve the problem, the quartiles represented exactly the same relative proportion of the problem-solving task. This accounted for any differences in the total times to complete the design task and gave an accurate picture of what happened during each quartile for each subject. Other studies such as Yashin-Shaw, (2001) and Middleton, (1998) have used similar methods to
represent verbal protocol data over time. The line graphs presented the distribution over time of the problem-finding episodes. The x-axis of the graph showed the time by quartiles, that is, the total data capturing time for each subject divided by four. The y-axis showed the number of problem-finding episodes that were used (e.g. see figure 4.2). The following sections present the results of each of the four subjects separately and then makes comparisons between the subjects.

**Results for Subject S1**

![Figure 4.2: Graph of problem-finding by subject S1](image)

As Figure 4.2 indicates, S1 verbalised problem-finding throughout the solving process except for quartile three. The number of problem-finding episodes identified was relatively small (8 in total). However, the data shows that problem-finding did occur in areas of the problem-solving process other than at the beginning.

**Analysis for Subject S1**

The lack of problem-finding in quartile three indicates that the subject may have been satisfied with the solution he had reached and therefore had little need to search for any other solutions and hence problems. The videotape showed that his design changed
marginally after quartile two because he had solved the problem. The remainder of the
time was spent on making sure the technical details of the drawing were accurate, i.e the
correct method of projection was used to produce the drawing.

**Results for Subject S2**

![Graph of problem-finding by subject S2](image)

Figure 4.3: Graph of problem-finding by subject S2

Figure 4.3 shows that this subject used problem-finding throughout the entire problem-
solving process. That is, the number of problem-finding episodes never reached zero. It
is evident that most of the problem-finding did occur at the beginning of the process but
there was also use of problem-finding during the whole process. A total of 17 episodes
of problem-finding were verbalised.

**Analysis for Subject S2**

The curve in figure 4.3 shows that S2 began to have an immediate reduction in the
number of problem-finding episodes from the commencement of the task. Quartile three
is the low point in the curve. This may indicate that the subject felt that he had solved
the problem early and that he was happy with the solution he had developed because he
was no longer finding any problems. The videotape reveals that after quartile two, this
subject made limited changes to the design. The videotape also helps explain the upward turn of the curve in the fourth quartile by showing that the subject was trying to overcome a design issue with one part of his solution. He though he had solved the problem but had to overcome a few more minor difficulties before he was happy the design would work.

**Results for Subject S3**

![Graph of problem-finding by time quartile for S3](image)

Figure 4.4: Graph of problem-finding by subject S3

Figure 4.4 shows this subject used problem-finding throughout the problem-solving process. A total of 30 problem-finding episodes were identified and the graph shows a steady decline in the use of problem-finding as the time went on.

**Analysis for Subject S3**

Subject 3 had a gradual decline in the use of problem-finding as the design unfolded. Unlike the other subjects, the lowest point in the problem-finding curve is at the end of the design process in quartile four. This may indicate that this subject may not have been satisfied with his design until the very end. The videotape shows that S3 continually changed his design throughout the process and that he used a trial and error...
method to solve the problem. This involved the subject exploring ideas and then
eliminating them. This method of problem-solving would be consistent with the curve
in figure 4.4. Although the number of problem-finding episodes becomes progressively
lower towards the end of the process, the curve never undergoes any dramatic changes,
and the minor changes seemed to coincide with the exploration and elimination of ideas.

**Results for Subject S4**

![Graph of problem-finding by subject S4](image)

**Figure 4.5: Graph of problem-finding by subject S4**

Figure 4.5 shows that his subject had a high number of problem-finding episodes
initially. However, while quartile three is the lowest point on the curve the number of
problem-finding episodes rose slightly towards the end of the design process.

**Analysis for Subject S4**

Even though S4 had considerably more experience than the other subjects, the shape of
his graph was similar in two ways. Firstly, the lowest point in quartile three indicates
that he had most of the problem solved before this time. Secondly, a small rise in the
curve in quartile four indicates that he was trying to finalise the design by ensuring the
fine detail of his design would work. The videotape verifies both of these explanations.
Comparisons across Subjects

Figure 4.6: Comparisons of the total problem-finding statements across all subjects.

Figure 4.6 shows the differences across subjects by having all four subjects represented on the same graph.

Analysis

Three important issues about problem-finding can be identified from the graphs in figures 4.2 to 4.6. Firstly, the graphs give confirmation to the notion that problem-finding occurred continuously (except for S1 in the third quartile) throughout the whole designing process. Secondly, the graphs show that all subjects had a decline over time in the number of problem-finding incidents that were verbalised. Lastly, the graphs also show similar patterns in the way that problem-finding increased in the fourth quartile when compared to the third quartile.

With regard to the first issue, knowing that problem-finding happened not only at the start of the solving process but that it also continued throughout is important to this study because it concurs with literature of this occurrence (Michael 1977). The finding
also advances the literature by providing more explanation on when problem-finding happens. This addresses Key Question number 1 which is ‘**When does problem-finding occur within the problem-solving process?**’ Getzels and Csikszentmihalyi (1976) in their study of art students also recognised that problem-finding doesn’t occur only at the beginning of the problem-solving process but can exist at other times. Part of their study quantified observable problem-finding behaviour in the problem formulation and solution stages. The findings presented here differ to those of Getzels and Csikszentmihalyi in that their study showed the existence of problem-finding during the solving process but not the relationship between problem-finding and the solving process over time, as depicted in the graphs in figures 4.2 to 4.6.

In regard to the second issue, which is that all subjects had a decline over time in the number of problem-finding incidents that were verbalised, figure 4.6 reveals that there was a drop off in the number of problem-finding episodes as time proceeded. For example, subject 3 started out with 12 in the first quartile and finished with 4 in the fourth quartile. Subject 2 started with 10 and finished with 3. The results presented here support the hypothesis that problem-finding in design decreases as the problem is solved. The reason for this could be in the way the subjects in this study solved the problems. That is, when faced with a new problem they may find many other problems. Hence the high occurrence of problem-finding identified initially. The subjects then may break the problem into smaller problems. They would find a problem and then give a solution to it. This process would repeat itself until the main problem was solved or a different idea was generated. Thus, the subjects would begin to run out of problems to find. As they reach a solution to the overall problem there would be no more problems to be found. This explanation may be a basis for a better understanding of the problem-finding process in designers.
Lastly, Figure 4.6 also shows that quartile three was a turning point in the frequency of problem-finding for most of the subjects. From quartile three to quartile four, the subjects generally had a slight increase in the number of problem-finding episodes. This trend may be explained by the following. At the end of the design process when the problem was nearly solved, the subjects appeared to be going back to recheck that their solutions from the previous three quartiles were workable and that they hadn’t missed anything. It was at this point that they all seemed to have found a few more last minute problems with their designs. They were in effect ‘tying up loose ends’ and so the number of problem-finding episodes increased slightly. The importance of this is that it may indicate that the low point of the curve is the point at which the subject is happy with their solution and the upturn of the curve may indicate that problem-finding is used to explore detail or for evaluative purposes.

In summary it can be seen that in addressing Key Question No. 1: **When does problem-finding occur within the design problem-solving process?** the study has found that each subject had examples of problem-finding throughout their design process. The number of problem-finding episodes for each subject seemed to be related to the amount of experience they have had as designers and their background knowledge. What one subject saw as a semantically rich problem was seen by another as semantically lean. It was also shown by graphing the frequency of problem-finding by time quartile (Figures 4.2 to 4.6) that, even though problem-finding occurred continuously, in all four subjects problem-finding was most evident at the beginning when interpreting the task. Problem-finding then slowly declined as more problems were identified and solved. Finally at the conclusion of the design process problem-finding episodes increased again as the
subjects rechecked their work. Therefore in addressing Key Question No1, in design tasks, problem-finding occurred throughout the whole problem-solving process.

In the following section Key Question No 2 will be discussed in terms of the four categories of problem-finding.

**Categories of problem-finding and their roles in designing**

To gain insight into the roles that problem-finding played in designing, a closer and more fine-grained examination of the data is presented. This section addresses Key Question No 2, which is; **What types of problem-finding occur in design and what roles do they play?** The first part of this question has been dealt with through the methodological approach this study has taken. The literature review enabled identification of four hypothesised problem-finding categories: Clarification, Elimination, Exploring Ideas and Lack of Knowledge. Each of these is now analysed in terms of their role in the design task that was researched in this study. This section accomplishes this by examining the data in two ways. Firstly, the data from all of the subjects pertaining to the problem-finding categories is explored using an holistic approach. That is, each category of problem-finding is examined individually in terms of how it was used during the problem-solving process. Secondly, the data from each subject is examined in the context of the four problem-finding categories and how they interacted with each other to achieve a solution, in order to understand further the roles that the different problem-finding categories played in solving design problems.

For ease of reference, an explanation of the four problem-finding categories, together with illustrated extracts from the data, is again presented.
1. **Clarification**: This is where a designer clarifies the initial given problem to be solved by finding other problems that need answers. In all subjects the clarification must refer back to the original problem. e.g. “Alright, well this bin the council already supplied, its obviously too high for a wheel chair person to open so I need to obviously make the lid smaller”. The implied sub-problem here, is that the bin is too high for a wheel chair person to open.

2. **Elimination**: This is where the designer eliminates a solution for a problem by finding a problem that makes the proposed solution unusable. e.g. “Oh this isn’t going to be able to lift the lid I don’t think”. The implied problem identified here is that the designer has found a problem with the solution he has been working on previously and so rejects it. It is a self-regulating process.

3. **Exploring ideas**: This is where the designer adds to the solution by finding a problem with the current solution. e.g. “but before you pull the rope a pin has to go in here somehow”. As he is designing, he finds a problem with a part of his solution and uses this to build on and rectify his idea.

4. **Lack of Knowledge**: This is where a person is unable to solve the problem through a lack of technical knowledge. The problem found here is that the designer doesn’t know how to solve the problem because he can not find a solution. e.g. “but I just don’t know how to get it to work”. In essence the designer has found a problem because he doesn’t know how to progress any further with his design.
Holistic Examination of problem-finding categories.

This section uses a broad approach, which combines the results of all subjects and presents the data in separate problem-finding categories. Currently the analysis has shown that all subjects used problem-finding but there has been no elaboration on the categories of problem-finding that were used. It is important to know when the categories of problem-finding were used because this may have implications for the teaching and learning of problem-finding.

The results of each of the four problem-finding categories that were identified in this study are presented in a graphical form, using a line graph. The number of episodes represented on the vertical axis of the graph show the number of times that each problem-finding category was identified for all subjects. The horizontal axis shows the time in quartiles. By combining these two variables it is possible to see when and how each of the problem-finding categories was used. The graphs do not indicate whether or not all subjects used each problem-finding category across the entire problem-solving process nor do they show if a subject used a problem-finding category at all. This question is addressed in the next section. The graphs do show the level of representation of a problem-finding category across all subjects; that is, to what degree a category of problem-finding was used to solve the problem.
Results for Clarification

Figure 4.7: Graph of Clarification

Figure 4.7 shows that Clarification was used in the first quartile only. The total number of Clarification problem-finding episodes for all subjects was 9. There was no evidence of Clarification existing in the second, third or fourth quartiles of the problem-solving process by any of the subjects.

Analysis for Clarification

A feature of the graph that stands out is that Clarification was only present for the first quartile of the design task. This may be explained by drawing on the literature. Ball et al’s (1994) notion that designers are reluctant to move away from their original designs, in combination with Schon’s (1988) theory that designers’ frame or set the context of the problem around an area in which they choose to explore, may provide an answer. If the subjects in this study stuck to their original idea they would have framed the context of the problem through Clarification early in the design task. Thus, if the context and idea had been set there would be no need for further clarification of the design. Hence the Clarification curve would end after the first quartile.
Results of Elimination

Figure 4.8: Graph of Elimination

Figure 4.8 shows that Elimination was used throughout the design solving process, but with some variation represented by an uneven curve. The first and second quartiles contained the most use of Elimination while the third and fourth quartiles contained less, indicating a decrease in the use of Elimination as the time went on and the problems began to be solved.

Analysis of Elimination

An explanation as to why Elimination was high in the first and second quartile and lower in the third and fourth quartiles may be that, in the second quartile, the subjects were still exploring ideas and subsequently eliminating the ones that didn’t work. After the second quartile, the use of Elimination reduced significantly. That is, they could not proceed to eliminate ideas if they were not generating any, as indicated by the concurrent drop in the Exploring Ideas graph (See figure 4.9).
Results of Exploring Ideas

Figure 4.9: Graph of Exploring Ideas

Figure 4.9 indicates that Exploring Ideas was used more than the other three problem-finding categories. This is evident in the high number of problem-finding episodes compared with the other three graphs. The use of Exploring ideas was most prevalent during the first and second quartiles. There was a significant drop in the 3rd quartile and an increase during the fourth quartile.

Analysis for Exploring Ideas

Figure 4.9 indicates that Exploring Ideas occupied the majority of problem-finding encountered during the problem-solving process when compared to the other graphs. An explanation for this may be found in the ill-defined nature of design problems and the way people engage in designing. As a design begins to unfold the designer may stick to the original idea. Protocol studies in designing show that designers rarely seek out many ideas and are unwilling to change to a completely new idea. They persevere with their designs, making continuous adjustments and modifications until a solution is reached (Ball et al 1994). This was the case with all of the subjects in this study. With this
notion in mind it may be that the large number of Exploring Idea episodes was a result of the subjects trying to fine-tune their initial ideas. Instead of developing a completely new idea when the one they were working on was deemed unsuitable, the subjects may have tended to explore ways of making their initial idea work. Finding new problems to solve by exploring and refining their ideas may have allowed the designs to evolve. In this sense, Exploring Ideas as a form of problem-finding would have facilitated the development of the final design.

**Results for Lack of Knowledge**

![Graph of Lack of Knowledge](image)

Figure 4.10 shows a graph of the use of Lack of Knowledge. Most of the episodes occurred in the first quartile with a decline in the number of episodes in the second and third quartiles. There were no episodes in the fourth quartile.

**Analysis of Lack of Knowledge**

Similarly to the other categories of problem-finding, Lack of Knowledge was at its highest level in the first quartile. This may indicate that while the subjects explored new ideas they may also have been evaluating their knowledge-base and consequently
rejecting ideas when they believed they lacked the knowledge to develop them.

Furthermore, a decline in the Lack of Knowledge episodes over the second and third quartiles may also indicate that as the subjects began to solve the problem they no longer needed to draw on their knowledge-base. Their initial choices, made during the first quartile, may have framed their solution in a way they knew was achievable, and therefore automatically avoided areas where their knowledge may be limited.

In the fourth quartile there are no episodes of Lack of Knowledge because the subjects’ designs are basically finalised, and they are unlikely to come across a problem at this stage of the design process where they lack the knowledge to continue.

**Combination of problem-finding categories across all subjects.**

![Figure 4.11: Graph of all problem-finding categories](image)

Figure 4.11: Graph of all problem-finding categories

Figure 4.11 provides a graph of the problem-finding episodes for all categories. The graph indicates that, for all problem-finding categories, the number of problem-finding episodes decreased from the beginning to the end of the problem-solving process, but that Exploring Ideas began to rise again at the end.
In summary, all categories of problem-finding except for Clarification, which was only used in the first quartile, were used throughout the design process. Overall, the number of episodes of each category declined as time proceeded.

**Individual examination of the interaction of problem-finding categories**

To present the data for this section, the coding tables from the methodology section are used. They have been reproduced here because they show the segment identifier, the transcript of the segment and what problem-finding category it belongs to. This presents the data on two levels. Firstly, the problem-finding category can be read in conjunction with the segment it represents. Secondly, the data shows a progressive representation of the problem-solving process over time. That is, the segments are in chronological order of occurrence. Therefore, by analysing the data in this fashion, not only can the type of problem-finding category be identified, but the interaction with other problem-finding categories can be examined also. The ticks in the columns under the Problem-finding Category section indicate the category of problem-finding used by that particular segment.

**Results for Subject 1**

<table>
<thead>
<tr>
<th>Segment Identifier</th>
<th>Segment</th>
<th>Coding category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Clarification</td>
</tr>
<tr>
<td>1</td>
<td>Alright well this bin the council already supplied its obviously too high for a wheel chair person to open</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>however that will give less room for rubbish</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>now if they were a wheel chair person they would obviously be a lot shorter so you’d have to put this lower</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>now I don’t know whether to just make it a smaller bin or to put something at the front</td>
<td></td>
</tr>
</tbody>
</table>
Umm I just thought about something if I got rid of if you don’t have a lid at the front you’re probably better off having it at a slight angle.

and the lid inside the tray you put the lid you virtually go up down sideways might have to make it a bit more round because you’ll need access for other things like plastic bags mightn’t fit in a square bin.

Umm that’s about it won’t need a lid there the top view will look like this.

actually what well do it I’ll make him lower about here so they can grab onto that easier.

Table 4.1: Coding table for subject S 1

Table 4.1 shows the coding table for Subject 1. The youngest and least experienced of the subjects used Exploring Ideas as the main form of problem-finding. This subject also used Clarification and Elimination to a minimal extent but did not use Lack of Knowledge. The sequencing of the problem-finding categories indicates that this subject used Clarification at the beginning then switched to Exploring ideas soon after. He continued to use Exploring Ideas for the most part, and at one stage towards the end, he switched to Elimination before going back to Exploring ideas.

Analysis for Subject 1

The results indicate that S1 used a relatively linear method to solve the problem. S1 was classified as an Advanced Beginner in designing. As such he had relatively little experience and so would be likely to stay within safe and known boundaries when trying to design the lid lifter. After a brief Clarification to orient himself with the problem, he mostly used Exploring Ideas to move his design forward and never really tried something new. Hence, he had to Eliminate an unworkable idea only once, and never had to use Lack of Knowledge as he did not include any ideas that were too technical for him.
### Results for Subject 2

<table>
<thead>
<tr>
<th>Segment Identifier</th>
<th>Segment</th>
<th>Coding category</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>I don’t know because they probably can’t use their feet cause they’re in a wheelchair</td>
<td>✓</td>
</tr>
<tr>
<td>17</td>
<td>Arr Umm I’m just going to just sort of put where to put the pedal so its not in the road of the wheels</td>
<td>✓</td>
</tr>
<tr>
<td>18</td>
<td>and just so it can just still sort of move with out getting caught on anything</td>
<td>✓</td>
</tr>
<tr>
<td>19</td>
<td>Somewhere where it is easy for them to push on</td>
<td>✓</td>
</tr>
<tr>
<td>24</td>
<td>Umm just just where to put the pedal for him and sort of how to have it all hooked up and everything so it will open.</td>
<td>✓</td>
</tr>
<tr>
<td>26</td>
<td>just trying, to think how it will work as well you know where you’re going to push and how it is going to open the lid</td>
<td>✓</td>
</tr>
<tr>
<td>35</td>
<td>I’m still thinking how it connects up</td>
<td>✓</td>
</tr>
<tr>
<td>37</td>
<td>Still how it sort of how the pedal would work because you’d push on it and it would open the lid but I don’t know how it would actually open the lid I don’t know how to set it up</td>
<td>✓</td>
</tr>
<tr>
<td>38</td>
<td>Because it would have to be on I don’t’ know pulleys or something to open it up and I don’t know where to put them or how they would work….</td>
<td>✓</td>
</tr>
<tr>
<td>43</td>
<td>It just how to get it to work….</td>
<td>✓</td>
</tr>
<tr>
<td>61</td>
<td>I’ve got to have enough room so that the pedal doesn’t hit dig into the ground</td>
<td>✓</td>
</tr>
<tr>
<td>63</td>
<td>umm I’m sort of thinking what angle to put it on as well so they can push it easy without moving the bin or making it fall over or anything</td>
<td>✓</td>
</tr>
<tr>
<td>72</td>
<td>and the rope to get to the pedal (The rope has got to get to the pedal somehow)</td>
<td>✓</td>
</tr>
<tr>
<td>101</td>
<td>I need something to tie off the rope as well</td>
<td>✓</td>
</tr>
<tr>
<td>121</td>
<td>I just need to think how thick I want it I don’t know if it should be too thick because it doesn’t need great strength or nothing</td>
<td>✓</td>
</tr>
<tr>
<td>131</td>
<td>ahh I don’t know if its rope some sort of plastic stuff that’s not stretchy its like firm</td>
<td>✓</td>
</tr>
<tr>
<td>134</td>
<td>I don’t know you could use anything rope some sort of plastic or the same material they use for tie downs.</td>
<td>✓</td>
</tr>
</tbody>
</table>

**Table 4.2: Coding table for subject S2**
Table 4.2 shows the coding table for subject 2, the year 11 student. Like Subject 1, Subject 2 mainly used Exploring Ideas to solve the problem. There was one occasion when Clarification was used and similarly to Subject 1, Subject 2 switched back to Exploring Ideas directly after. Segments 37, 38 and 43 show that this subject used Lack of Knowledge three times consecutively. A closer examination of the segments indicates that the use of Lack of Knowledge were all associated with the same issue of how to get his idea to work. After this, he then switched back to Exploring Ideas for the remainder of the task.

**Analysis for Subject 2**

Subject 2 went about solving the problem by firstly coming up with a single idea early in the task. From then on he tried to build on the idea by finding other problems which would overcome some of the difficulties he came across. The use of Exploring Ideas in segments 61-134 was associated with solving the Lack of Knowledge problems he encountered prior to this. In essence, by realising that he didn’t have the ability to solve the problem, he was forced to seek out other solutions. This may indicate that when a person identifies weaknesses in their knowledge-base they feel the need to explore more ideas to solve a design problem. Lack of Knowledge was immediately followed by Exploring Ideas in all segments for all subjects. Therefore Lack of Knowledge may have lead to the exploration of new ideas and may have been a problem-finding technique that would overcome or move around difficulties considered to be of a blocking nature.
### Results for Subject 3

<table>
<thead>
<tr>
<th>Segment Identifier</th>
<th>Segment</th>
<th>Coding category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>And they can’t open the lid so that’s got to be modified somehow without altering the bin</td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td>It’s got to be picked up in the same way</td>
<td>✓</td>
</tr>
<tr>
<td>5</td>
<td>so it’s got to be able to get out of the house easily and go over to the bin</td>
<td>✓</td>
</tr>
<tr>
<td>6</td>
<td>and it’s got to be cheap as well</td>
<td>✓</td>
</tr>
<tr>
<td>7, 8</td>
<td>I’m thinking if they can’t lift it up and put it in so they need something that can lift it up for them</td>
<td>✓</td>
</tr>
<tr>
<td>12</td>
<td>But just make sure there are no steps</td>
<td>✓</td>
</tr>
<tr>
<td>13</td>
<td>The bin itself can’t be changed because it’s got to be picked up...</td>
<td>✓</td>
</tr>
<tr>
<td>17</td>
<td>but that might cost a bit of money</td>
<td>✓</td>
</tr>
<tr>
<td>22, 23</td>
<td>see you can’t have something that clamps to the bin because that would be lifted when the garbage truck comes...</td>
<td>✓</td>
</tr>
<tr>
<td>24, 25</td>
<td>and we can’t really alter the height of the bin either because then the truck wouldn’t be able to pick it up as easy</td>
<td>✓</td>
</tr>
<tr>
<td>27, 28</td>
<td>probably not from this angle because the bins going to open up this way</td>
<td>✓</td>
</tr>
<tr>
<td>36</td>
<td>There must be some way for it to tip so that things get tipped into the bin</td>
<td>✓</td>
</tr>
<tr>
<td>40</td>
<td>just got to make sure that that’s not too stiff to lift</td>
<td>✓</td>
</tr>
<tr>
<td>42</td>
<td>So once it gets to the top it’s got to somehow be able to tip</td>
<td>✓</td>
</tr>
<tr>
<td>47</td>
<td>oh this isn’t going to be able to lift the lid I don’t think…</td>
<td>✓</td>
</tr>
<tr>
<td>53</td>
<td>there’s something that’s got to come up and lift the handle before this reaches the top for that to tip down</td>
<td>✓</td>
</tr>
<tr>
<td>55, 56</td>
<td>ahh it couldn’t be actually because then the truck couldn’t pick it up</td>
<td>✓</td>
</tr>
<tr>
<td>61, 62</td>
<td>see the hardest thing with this is getting it into the ahh handle itself because once there finished it will have to be detached from the handle</td>
<td>✓</td>
</tr>
<tr>
<td>68 - 70</td>
<td>now somehow this has got to go up to probably about this height here and then actually get tilted down so the contents goes into the bin</td>
<td>✓</td>
</tr>
<tr>
<td>73</td>
<td>because if it was here it wouldn’t be able to be tilted</td>
<td>✓</td>
</tr>
<tr>
<td>76</td>
<td>it would also have to be attached somehow to the ground so it can’t be stolen…</td>
<td>✓</td>
</tr>
<tr>
<td>88</td>
<td>no it would have to be separate actually…</td>
<td>✓</td>
</tr>
</tbody>
</table>
but before you pull the rope a pin has to go in here somehow…

just the hardest thing would be getting it into the handle

and somehow that’s got to be pushed into the handle because it can’t just stay there.

Now I’ve just got to work on the handle here

now somehow this bit here has got to go in its got to go into there and possibly maybe twisting down here or something

Actually the bin’s not that high really

the you just have to make sure they take the pin out when the truck comes

you just have to make sure that once that’s up the top and you let go of the handle it’s not going to all of a sudden wind and come flying down

<table>
<thead>
<tr>
<th>99</th>
<th>but before you pull the rope a pin has to go in here somehow…</th>
<th>✓</th>
</tr>
</thead>
<tbody>
<tr>
<td>107</td>
<td>just the hardest thing would be getting it into the handle</td>
<td>✓</td>
</tr>
<tr>
<td>120, 121</td>
<td>and somehow that’s got to be pushed into the handle because it can’t just stay there.</td>
<td>✓</td>
</tr>
<tr>
<td>128</td>
<td>Now I’ve just got to work on the handle here</td>
<td>✓</td>
</tr>
<tr>
<td>134, 135</td>
<td>now somehow this bit here has got to go in its got to go into there and possibly maybe twisting down here or something</td>
<td>✓</td>
</tr>
<tr>
<td>137</td>
<td>Actually the bin’s not that high really</td>
<td>✓</td>
</tr>
<tr>
<td>153</td>
<td>the you just have to make sure they take the pin out when the truck comes</td>
<td>✓</td>
</tr>
<tr>
<td>179</td>
<td>you just have to make sure that once that’s up the top and you let go of the handle it’s not going to all of a sudden wind and come flying down</td>
<td>✓</td>
</tr>
</tbody>
</table>

| Table 4.3: Coding table for subject S3 |

Subject 4, whose data is represented by table 4.3 used problem-finding more than the other subjects. He used all categories except Lack of Knowledge. The sequencing of his problem-finding shows that this subject used Clarification at the beginning then switched to Exploring Ideas before switching to Elimination. After this point there was continuous switching between Elimination and Exploring ideas for the remainder of the task.

*Analysis for Subject 3*

The continuous switching between the two categories of Elimination and Exploring Ideas used by S3 had some pattern to it. That is, Exploring Ideas was generally used in small groups of two or three statements with Elimination being used on its own. This may indicate that the two forms of problem-finding were working together to solve the problem. Reading the segments and reviewing the video gives a better indication of the role that these two categories played in solving this problem. For example, segment numbers 27 and 28 eliminate the idea of the placement of a lifting device on the bin generated earlier. Switching to Exploring Ideas, Segment 36 developed a new concept.

By applying his knowledge the subject knew that it was possible for the design to be
tipped so that the rubbish would fall into the bin. He just didn’t know how to do this yet. This set the foundation for the following two segments 40 and 42, which explored this idea further. After this the subject switched back to Elimination in segment 47, he realises the concepts developed in the previous segments were not workable. This pattern of switching between Elimination and Exploring Ideas continued for the remainder of the problem-solving process.

This grouping of two or three segments found in Exploring Ideas may be a result of the subject having to find a new concept then build on it. In this way he could slowly develop the concept without having to back-track. This happened until he reached a point where he realised that a part of the concept would not work. He then eliminated the idea quickly and proceeded to explore other options. This seems to suggest that the two categories of Exploring Ideas and Elimination often worked in tandem for this subject to improve the design process and work towards a solution.

**Results for Subject 4**

<table>
<thead>
<tr>
<th>Segment Identifier</th>
<th>Segment</th>
<th>Coding category</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>and I’m just writing down height as one of the main issues I need to address</td>
<td>✓</td>
</tr>
<tr>
<td>15</td>
<td>the problem they also have is that it is awkward</td>
<td>✓</td>
</tr>
<tr>
<td>25</td>
<td>the only other thing I’m thinking of at the moment is... is manoeuvring the bin umm</td>
<td>✓</td>
</tr>
<tr>
<td>33</td>
<td>ahh I’ll have to design a couple more...</td>
<td>✓</td>
</tr>
<tr>
<td>36</td>
<td>probably some information I lack at this time is to do with disabled people and their capabilities and heights of a wheel chair</td>
<td>✓</td>
</tr>
<tr>
<td>50</td>
<td>suppose the other real concern is the manoeuvrability of the bin</td>
<td>✓</td>
</tr>
<tr>
<td>57</td>
<td>I’d have to look into that</td>
<td></td>
</tr>
</tbody>
</table>
Table 4.4: Coding table for subject S4

Table 4.4 shows the coding for the eldest and most experienced subject S4. In a similar fashion to S1 and S3, this subject began the solving process by the use of Clarification. The difference between S4 and the others is that while using Clarification early in the process, S4 Explored an idea at segment 25 and then switched back to Clarification in segment 33. The switching from Clarification to another category and then back to Clarification did not happen in any of the other subjects. For the remainder of the solving process S4 switched between Exploring Ideas and Lack of Knowledge.

Analysis of Subject 4

The patterns found in the data of S4 were similar to those for S3. However, whereas S3 switched between Exploring Ideas and Elimination, S4 switched between Exploring Ideas and Lack of Knowledge. Where S3 used Elimination to indicate a change in his thinking patterns, S4 used Lack of Knowledge. They both used their pattern change mechanisms to achieve a similar outcome but chose to take different approaches to reach their final decision. S4, who was classified as a Proficient designer, was an older and more experienced designer with a wider knowledge-base. Unlike some of the other Subjects he would be more willing to take risks when designing. As such he came up with more varied and realistic ideas. Proficient designers use their intuition (Patel and Groen 1991). As such S4 didn’t need to verbally eliminate an idea as unworkable as he
probably did this automatically before using the idea. He did realise that he needed more technical knowledge in some areas. This however did not hamper his design process.

So that he could order his ideas, S4 also used Clarification at times throughout the design process. This enabled him to refer back to the initial problem to be sure he was meeting the stated criteria. This was unlike the other Subjects who used Clarification only initially. Perhaps this shows that, as the Proficient designer was able to do this, his designs were more likely to be workable and meet the needs of the initial design brief.

In summary, a pattern emerged suggesting clear differences in the frequency of use and the manner in which these people with different levels of expertise used problem-finding.

Subject 1 used mainly Exploring ideas in an uncomplicated and linear method. That is, he rarely used any other problem-finding category to solve the problem.

Subject 2 expanded on the methods taken by Subject 1 in that, as well as using mainly Exploring Ideas, he combined this with Lack of Knowledge. The latter of which was used to overcome a problem that was considered to be of a blocking nature.

Subject 3 had continuous switching between Exploring Ideas and Elimination. This allowed for concepts to develop without having to back-track in the design. This was different from Subject 2 in that there was a constant switching between the two problem-finding categories. It was interpreted that S3 was using the two categories in combination to solve the problem.
Subject 4 also used a continuous switching method. Unlike Subject 3, this subject switched between Exploring Ideas and Lack of Knowledge. Probably because he was more experienced than the others he was able to realise that he needed more technical knowledge to solve a problem. He acknowledged this automatically and was able to continue with the solving process undeterred. This level of control in his cognition suggests that he was developing expertise for design tasks.

In summary, as the designers became more experienced they not only used different types of problem-finding but also used the problem-finding in differing ways to reach a solution. The following section expands on this idea by looking more closely at the ways in which the different problem-finding categories interacted with each other.

**Results of the sequencing of patterns between categories.**

<table>
<thead>
<tr>
<th>First segment</th>
<th>Second segment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clarification</td>
</tr>
<tr>
<td>Clarification</td>
<td>4</td>
</tr>
<tr>
<td>Elimination</td>
<td>0</td>
</tr>
<tr>
<td>Exploring Ideas</td>
<td>2</td>
</tr>
<tr>
<td>Lack of Knowledge</td>
<td>0</td>
</tr>
</tbody>
</table>

**Table 4.5: Correlation of patterns of sequencing between categories**

Table 4.5 presents an analysis of the patterns of sequencing that appeared in the protocols. It shows the frequency of when two categories were used in combination in a forward direction to solve the design problem. That is, the left column is the first segment and the top row represents the segment following immediately after. For example, to find the number of times when Clarification was used immediately before Lack of Knowledge, follow down the left column until Clarification is found. Correlate this with the Lack of Knowledge category in the top row. The answer is one. This means that Clarification was only used once immediately before Lack of knowledge.
This table is useful because it suggests relationships between category combinations in solving design problems.

The following analysis examines each category separately. It makes reference not only to table 4.5 but also to the other categories of problem-finding by referring to Tables 4.1 to 4.4. This enables an investigation into how the subjects used the specific categories to solve the design problem. By analysing in this fashion, a richer understanding of the role that problem-finding played in this designing is provided and comparisons may be made between the different levels of expertise that were involved.

**Analysis of the sequencing of patterns between categories.**

*Clarification to Clarification*

Clarification was used by all subjects and was confined mainly to the beginning of the problem-solving process. This would not seem unusual because a person would normally have to clarify what is being asked, the limitations of the problem and the type of environment for which the problem is to be solved before solving can begin.

According to table 4.5, there were four occasions when Clarification led directly into the use of more Clarification. Most of these were situated relatively close in time to each other except for one occasion (Subject 4, segments 2 and 15) (See table 4.4). This is the only moment that a significant amount of time separated two segments of Clarification immediately following each other. Only S1 and S4 tended to follow their initial Clarification ideas through to the end of the design. The other two, S2 and S3, had left their clarification ideas behind within the first quartile. This meant that they
either had a clear direction of what they were going to design already in their heads or that they had not considered the initial limitations placed on the design.

The reason for this difference may lie in the way the more experienced designer (S4) went about clarifying the problem. Unlike the other three, S4 actually wrote down on his sheet of paper the words he was saying at the time. This appeared to be his way of clarifying the design situation and making sure it was clearly the focus of the design. For instance, in segment 2 he speaks about writing down height as a main issue. He also writes down ‘awkward’ but fails to verbalise this. By writing down notes before he began to sketch, S4 may have been using a more efficient method of documenting what he had to do. This is important because the two main issues he wrote on his sheet of paper were the focus of his design and he kept on reflecting back to this page to check if he was on track. By initially clarifying the problem situation in writing, S4 set the foundation for the successful completion of the design task in a simple and methodological way.

S1’s main interest in clarification was the height of a person in the chair. His final design was a very simple change to the shape of the wheelie bin. Like S4, S1 used his initial clarification of the design situation to drive his thoughts and to become the focus of his final design. However, S1 only used clarification once and had limited engagement in looking for other possible solutions.

S2 began to clarify approximately halfway through the first quarter. His clarification was not to do with the initial problem situation but more so with a sub-problem, a problem he found. His design involved a pedal to open the lid of the wheelie bin and
rope and pulley system to connect the pedal to the lid. Although S2 did use clarification, it was to solve a sub-problem, one which he had difficulty with.

S3 clarified the problem clearly and concisely at the beginning. He verbalised things like “…they can’t open the lid…”, “it’s got to be picked up in the same way” and “…its got to be cheap…”.

In summary, each Subject at the beginning of the design process used Clarification. This was so that they could interpret what was required in the design brief before they began to solve the problem.

**Clarification to Elimination**

At no time did any of the subjects use Elimination immediately after Clarification. Clarification is concerned with interpreting what the problem is about rather than finding solutions, so eliminating ideas would not be necessary at this early stage of the process. That is, the subjects had not explored many ideas at this point in the designing phase and therefore had nothing to eliminate from their designs.

**Clarification to Exploring Ideas**

Clarification was used once by each subjects as a lead into Exploring Ideas. An explanation may be that, once a person clarified what was required of the design task, they began to search for ways to solve the problem. Hence, they would have begun to explore ideas immediately after making clear to themselves what was required of the design task.
Clarification to Lack of Knowledge

This sequence was used on one occasion by S4 (refer to table 4.4 segments 33 – 36). The context of the verbalisation according to the videotape was that he had realised that he needed to come up with some more ideas to solve the problem. In trying to generate new ideas, segment 36 reinforces the fact that he didn’t know much about disabled people. He realised that he needed more information to solve the problem successfully. Hence, he switched from clarifying what he had to do to solve the problem to identifying that he lacked the knowledge to complete the design.

Elimination to Clarification

As with the reverse of this combination of categories, none of the subjects used this sequence. This was unexpected because, after the elimination of a possible solution, one would think the subjects would go back and re-clarify what they had to do before they came up with a new idea. The reason for this may be that they had not developed sufficient ideas to enable the use of Elimination at an early stage in the design process when Clarification was most prevalent. Hence, if they had no ideas to eliminate then the switch from Elimination to Clarification would not be present.

Elimination to Elimination

This sequence appeared only with S3 and exclusively in the first quartile. Represented by segments 13 to 28 in table 4.3, the data indicates that for the most part, the use of Elimination was related back to the Clarification used in segments 2 to 6. The Elimination to Elimination sequence tended to happen in a chunk at one particular point and for one subject. This may be because the subject was eliminating ideas that either didn’t fit the situation he had previously clarified or were not in keeping with the ideas he had explored earlier in segments 7 to 12. This meant that a large proportion of the
latter part of the first quartile was dedicated to eliminating ideas he had already thought about. Once he had a clearer picture of his direction he was able to move on and explore more ideas and in so doing advance the design. As noted earlier, it is possible that S4 also engaged in sequencing Elimination, but had not verbalised it, as it was automatic. If this is true, then it is not surprising that S1 and S2, with less experience would have had fewer ideas to eliminate in a sequence.

Elimination to Exploring Ideas

This sequence occurred seven times. Six of those occurrences were with S3 and one was with S1. The S1 occurrence was towards the end of the design task. In terms of time, the two segments were a considerable distance from each other. In terms of context they were unrelated. Therefore, no conclusions are drawn regarding the contribution of this sequence by S1.

Most of the other six occurrences of this sequence undertaken by S3 were closely related in both time and context. For example, the exploration of an idea found in segment 36 was a direct result of the Elimination in segment 27. That is, the subject had eliminated a part of the idea of having a device to pick up the rubbish and drop the rubbish in the wheelie bin from a particular angle. This Elimination then enabled him to move on and look at exploring other methods to solve the problem as identified in segment 36. The subject explored new ideas that would allow the rubbish to be picked up, but only ideas that did not include using the method he had eliminated in segment 27. In this sense, the elimination was a way of engaging the search for new ideas. The same notion applies to segments 47 to 53, 55 to 61 and 73 to 76. The other sequences of 88 to 99 and 137 to 153 are not directly related to each other in time or context. Therefore, in some situations Elimination was found to lead to the use of Exploring
ideas if they were used within a close time frame. This controlled switching for S3 can be interpreted as an indication of his developing expertise.

**Elimination to Lack of Knowledge**

At no time during the sessions did any of the subjects use the sequence of Elimination to Lack of Knowledge. This might have happened because once an idea has been eliminated the subjects would have been more likely to explore new ideas before then realising they lacked the knowledge to make these new ideas workable.

**Exploring Ideas to Clarification**

This sequence was found two times, once each for subjects S2 and S4. As with all the Clarification segments these two occurred in the first quartile of both subjects’ verbalisations. It was the only time subject S2 used Clarification during the whole design task. The context and timing of the segments where these two subjects used this sequence of problem-finding may indicate that finding problems by exploring ideas may have been used for further clarification of the problem. That is, finding new problems by exploring ideas could mean the subject may have had to check that the new idea fitted the original overall problem and hence this led to the clarification problem.

**Exploring Ideas to Elimination**

This sequence was utilised seven times, once by S1 and six times by S3. The context of this sequence of the two segments (29 and 37) for S1 seemed unrelated. The time difference between the two segments was also great and therefore, based on these two characteristics, it was accepted that for S1 the two segments were unrelated.

S3 did have a relationship between this sequence and the way in which he designed. This subject would Explore Ideas and then use Elimination immediately afterwards.
when testing that the idea would work. Context and time directly related all the segment pairs of 12 -13, 42 - 47, 53 - 55 and 68 –73. That is, the first Exploring Ideas segment appeared to enable the Elimination segment to happen. The only segment pairing of this type that was not related by context and time was 76 – 88. Interestingly, the inverse of this sequence (Elimination to Exploring Ideas) was also identified seven times for the same subjects in the same proportion of 1:6.

**Exploring Ideas to Exploring Ideas**

By far the most used sequence was the combination of Exploring Ideas and Exploring Ideas. This sequence was identified twenty five times out of a total of 64 statements across 4 subjects. S4 had this combination once and this was towards the latter part of the design task. S1 used it four times during the first and second quartiles. S3 used it nine times mainly in the second and third quartiles. S2 used it ten times spread throughout the whole design task. These figures place each of the subjects into two clearly separate groups. The first group consisting of S4 and S1 who only used this sequence a comparatively small number of times compared to the other group of S2 and S3. For clarity, each subject will be discussed separately within groups. The first group will be discussed followed by the second group.

**Group 1**

Subject 4’s use of this sequence was very limited. The only time it was verbalised was for segment pairs of 91 – 94. This subject being the eldest and most experienced may explore an idea and then focus on ways to implement that idea. Ahmed et al (2003) studied the differences between novice and expert designers and found that experienced designers made a preliminary evaluation of their designs before deciding to go any further with them, whereas novice designers used a trial and error method to work toward a solution. In this sense, the lack of use of Exploring Ideas as a sequence may
not seem unusual. The experienced subject would firstly explore the ideas to find the problem and would then evaluate its use instantaneously. The evaluation may consist of using some of the other problem-finding categories such as Lack of Knowledge or Clarification but he would not explore other ideas until the evaluation of his current idea had been completed.

Subject 1, the least experienced used this sequence four times but it was this sequence that dominated his designing method. Of the four sequences identified, segments 10–11 were the only segment pair related by time and context. An explanation for the small usage of this sequence may be found from Christiaans and Dorst (1992) who noted that Junior Novices tended not to gather a lot of information but rather solve simple problems without recognising other potential solutions or difficulties. In this sense, S1 may have simply built on his initial idea in small chunks. Unlike S4, he had no need to evaluate his ideas to any degree, but in his case it was because he had not recognised any external influences on his design. Therefore he developed his design in a very straightforward manner by exploring one idea after the other without giving any justification for changes he may have made. He may have been using a trial and error method without verbalising the errors.

**Group 2**

S3 used this sequence nine times, the majority of which were related in both time and context. S3 would explore the ideas as a sequence and then switch to a form of evaluation, namely Elimination. By doing this he seemed to be able to develop a better sense of direction for his design while at the same time considering the wider constraints and difficulties of the design task. S3 would explore multiple micro-ideas
about a particular part of his design, evaluate the idea and then move on. This process allowed him to progressively build his solution.

S2 used this sequence ten times. Of these nine of them were related in both time and context. The difference between S3 and S2 is that whereas S3 used this sequence in conjunction with Elimination apparently as an evaluation tool, S2 rarely used other categories. Although S2 was Exploring Ideas, the context of the ideas seldom resulted in a solution or a step forward in the design process. He seemed to get bogged down in the detail of how to make the design work and, possibly because he had no answers, he was forced to continue exploring more ideas. Getting stuck in the design is a phenomena highlighted by Atman et al (1999). Although their study describes getting stuck in the problem definition stage there would be no reason why this couldn’t also occur in other problem-finding episodes in other stages of the design process as appeared to be the case with S2.

**Exploring Ideas to Lack of Knowledge**

This sequence was identified three times, once for S2 and twice for S4. Of the three occurrences, one by each subject was considered to be relevant in both time and context. On both of these occasions, the subjects appeared to have explored an idea and then realised that they did not possess the knowledge or experience to continue with the idea.

**Lack of Knowledge to Clarification**

At no time during the sessions did any of the subjects use the sequence of Lack of Knowledge to Clarification. This may be because as a subject realised that he could not continue with his current idea due to his lack of technical knowledge, he would move on
to explore a new idea or eliminate the one he had been working on. It would be unnecessary for him to go back to clarify the design brief at this time.

**Lack of Knowledge to Elimination**

At no time during the sessions did any of the subjects use the sequence of Lack of Knowledge to Elimination verbally. This was unexpected because it is feasible that as a subject realises that they did not possess the knowledge to solve a problem they may then eliminate that idea from their design. This was not the case with these subjects. They simply seemed to ignore this problem and started to explore other new ideas. Perhaps this was because as the Subjects realised that they lacked the technical knowledge to continue with their design they automatically eliminated the idea without verbalising it. Rather than verbalise this Elimination, they simply moved on to exploring new ideas that may work instead. The Elimination may have been implicit rather than explicit.

**Lack of Knowledge to Exploring Ideas**

The sequence of Lack of Knowledge to Exploring Ideas was identified 4 times, once by S2 and three times by S4. All of these were related in time but none were related in context. S4 continued with the design as though his Lack of Knowledge at that point in time wasn’t an issue by moving on to explore new ideas and solutions. S2 conceded that he didn’t know how to get the design to work but persisted by also exploring other ideas. This phenomenon was mentioned in the previous section also. After realising they lacked the required knowledge to complete the design they either ignored this fact or implicitly eliminated the idea and then went on to explore other ideas.
**Lack of Knowledge to Lack of Knowledge**

This sequence was identified 3 times, once for S4 and twice for S2. The sequence for S4 was unrelated in both time and context and therefore considered not relevant. The sequences for S2 were related in both time and context. During the design process, S2 had some difficulty with one particular part of his design. He spent a lot of time thinking about how he was going to get his idea to work. Although he had realised that he didn’t know how to do this he persisted, for a long period of time and often had to be asked to continue talking. It was during this time that he re-verbalised his inability to solve the problem because of his Lack of Knowledge. Therefore, at times in the design process, one episode of Lack of Knowledge may have led to another as a Subject realises that he can not make his design work. He may try to change it to make it work for him, but his Lack of Knowledge in this area may hamper him again as he finds yet another problem in his design. A lack of experience may also explain this persistence.

In summary, the four categories appear to play important roles in how the design process proceeded. Clarification was used mainly at the beginning of the problem-solving process, in combination with Exploring Ideas, Lack of Knowledge and itself, but not with Elimination. This indicates that none of the subjects eliminated an idea before they checked to see how it fitted in with the situation, nor did they go back and clarify a new idea after they had eliminated one. The analysis also indicated that the less-experienced subjects ignored the original situation once they had begun to develop their ideas, apparently because they were ‘bogged down’ trying to make their ideas work. This was not the case with Subject 4 who continually reflected on the original situation and was able to move on with his design when potential problems were found.
Elimination was used in combination with itself and Exploring ideas. For the most part, Elimination was utilised in a way that engaged the search for new ideas. This was achieved through Exploring Ideas and then Eliminating them if they didn’t fit the situation.

Exploring Ideas was used with all the categories. This confirms the importance placed on the exploration of ideas in models such as the Geneplore model by Finke, Ward and Smith (1992). However, the way in which Exploring Ideas was used in conjunction with the other problem-finding categories indicates that the interaction of these categories, even to small extents, was important in solving this design problem. The use of Exploring Ideas with other categories appeared to allow for the problem solver to make a decision as to whether to persist with an idea or to forget about it.

Lack of knowledge was mainly used in combination with Exploring Ideas and itself. The way in which it was utilised appeared to vary as a function of experience. The less experienced subjects tended to acknowledge their Lack of Knowledge but persisted by trying to find a solution. The more experienced understood that a lack of technical knowledge should not be an issue or could be corrected later, and then continued on with other parts of the design. In understanding the interaction between the problem-finding categories a clearer picture of how problem-finding enabled the subjects to solve design problem emerged.

The next Chapter presents conclusions about the overall findings of this study. The findings are presented in the context of the literature identified in Chapter 2 and the research questions. The contributions of the study are then outlined and areas for further research identified.
Chapter 5: Discussion and Conclusions

Introduction

This study was undertaken for four reasons. Firstly, it was interested to investigate the notion of problem-finding as identified in Getzels & Csikszentmihalyi’s 1976 study of the fine arts, ‘The Creative Vision’, and to apply this to Industrial Designing. Getzels & Csikszentmihalyi (1976) found that a person’s problem-finding ability was a predictor of their creativity ability. It was believed that further work in the area of problem-finding may refine and tease out this concept, and, in so doing, lead to a better understanding of designing, more creative designs and better methods to teach design.

Secondly, little research has been done in the area of problem-finding in general. Formerly, problem-finding had been referred to by terms such as problem formulation, problem posing, problemizing, problem expression, problem construction, problem definition, and problem identification. In Chapter 2, this study argued that these terms seemed to refer to the process of initially identifying a problem to be solved. Evidence is adduced in this dissertation that problem-finding is more than the initial identification of a problem, it appears to occur throughout the entire design process. Therefore a clear definition for problem-finding is required to allow for the examination of problem-finding in an industrial design context. Hence, a second aim of this study was to clarify the nature of problem-finding.

Thirdly, problem-finding is not generally recognised in curriculum documents in terms of pedagogy, and hence little is know about its role as a possible strategy which students may employ in solving high school design problems. Therefore through investigating problem-finding, it was envisaged that future curriculum may include problem-finding as a part of the recommended pedagogy.
Fourthly, literature suggested that design ability varied with experience. Therefore, it was hoped to be able to show changes in problem-finding ability with students of different levels of expertise.

To examine these aims, the study used a Think Aloud method to gather data from three high school design students and one design teacher all with different levels of expertise. The data was analysed in terms of the Key Research Questions that are discussed in the next section.

This chapter is organised in the following way. Firstly, the findings of the research questions are presented and discussed, then the contributions of this study are summarised and finally suggestions for further research are presented.

The findings to the research questions

To examine problem-finding in terms of these four aims, the study identified two Key Research Questions. They are:

1. When does problem-finding occur within the design problem-solving process?
2. What types of problem-finding occur in design and what roles do they play?

Each Key Research Question is discussed separately in terms of the literature identified in Chapter 2 and the data analysis in Chapter 4.

Discussion on Research Question 1.

Research Question 1 was developed from the argument in Chapter 2 that most research on problem-finding is based on the assumption that problem-finding tends to happen
only at the beginning of the problem-solving process (Dillon 1982; Reite-Palmon et al 1998; Jay and Perkin 1997). Getzels & Csikszentmihalyi (1976) did acknowledge that problem-finding does occur during the solving stage but did not address the question of when that might take place. Hence, Key Research Question 1 arose.

An initial answer to Key Question 1 is that the analysis of the results from the examination of the four subjects indicates that problem-finding occurred throughout the whole problem-solving process. Having evidence that problem-finding occurred throughout the design process is important because it confirms one of the arguments developed in Chapter 2. A more detailed analysis of the data showed that problem-finding was more prevalent at the beginning of the design process, dropped off towards the middle stages and lifted slightly toward the end of the solving process. This finding supports the argument in Chapter 2 that problem-finding is more than the identification or breaking down of the problem before commencing the solving process.

![Figure 4.6: Comparisons of the total problem-finding statements across all subjects](image)

**Figure 4.6: Comparisons of the total problem-finding statements across all subjects**

In contrast to most of the literature on problem-finding/solving, figure 4.6 shows (a) that problem-finding did occur as the solving process progressed and (b) how this was distributed across the problem-solving process.
An implication is that, in the future, design teachers may be able to help students improve their designs by making them aware of the ways in which problem-finding can enhance their thought processes.

**Discussion on Research Question 2.**

**What types of problem-finding occur in design and what roles do they play?**

Key Question 2 was developed from the argument that problem-finding was more than the finding of an initial problem to be solved. Chapter 2 argued that in addition to this definition, problem-finding was also evident in two forms. The first seems to occur when a person runs into trouble and has to change their mind or look at the problem in a different way than they had originally thought possible. The second form is when a person creates a useful situation that will move the design forward by creating new questions for inquiry. Hence, it was hypothesised that problem-finding is both the detection of difficulties and the discovery of new questions for scrutiny as the design evolves.

Key Question 2 was addressed by investigating differences between the problem-finding episodes identified in Key Question 1. The results were analysed in terms of the four problem-finding categories synthesised in Chapter 3. They were Clarification, Elimination, Exploring Ideas and Lack of Knowledge. The results indicated that all four categories of problem-finding were used. However not all subjects used all the four categories, and they used them in different combinations which seemed to stem from their level of design experience. This result suggests that problem-finding may be
undertaken in different ways depending on the level of expertise of the person solving the problem.

To enable a comprehensive understanding of the role of each category of problem-finding, an analysis at two levels was undertaken. Firstly, the relationship between the problem-finding categories and when they were used was looked at. Secondly, the relationship between the problem-finding categories and how they interacted with each other to solve the problem was investigated. An initial analysis of the results showed that there was variation between the subjects in terms of when and how they used problem-finding.

Subject 1, the least experienced designer, focussed on Exploring ideas in an uncomplicated and linear method. That is, he rarely used any other problem-finding category to solve the problem. Subject 2 expanded on the methods used by Subject 1 in that, as well as using Exploring Ideas, he combined this with recognition of Lack of Knowledge. However, his use of Lack of Knowledge was grouped, without any switching back to other categories, indicating that he was trying to overcome a problem that he considered to be of a blocking nature. Subject 3 had continuous switching between Exploring Ideas and Elimination. In a similar manner, Subject 4 also used continuous switching. However unlike Subject 3, Subject 4 switched continuously between Exploring Ideas and Lack of Knowledge.

These results are interpreted as indicating a progressive development in the ability to use problem-finding, as their level of expertise developed. Subjects 3 and 4, the most experienced designers, were able to apply several different categories of problem-finding in combination to solve a design problem. This is evident by the switching
between categories. The less experienced subjects tended to use one or two categories of problem-finding and tended not to use the categories with each other. In these cases the categories were generally used by themselves in stand-alone situations.

Having this knowledge of how these subjects combined different kinds of problem-finding may enable design teachers to educate their students about the different categories of problem-finding, and how to combine them, in order to improve the students’ ability to design.

The second level of analysis for Key Question 2 was based on the switching between problem-finding categories identified in the previous analysis. The switching process prompted an inquiry into why the subjects switched between the categories. Hence the sequencing of patterns between the problem-finding categories was analysed.

The findings of this analysis showed that Clarification was used mainly at the beginning of the problem-solving process. It was used in combination with Exploring Ideas, Lack of Knowledge and itself, but not with Elimination. This indicates that none of the subjects eliminated an idea before they checked to see how it fitted in with the situation, nor did they go back and clarify a new idea after they had eliminated one. The analysis also indicated that the less experienced subjects ignored the original situation once they began to develop their ideas, apparently because they were ‘bogged down’ trying to make their ideas work.

Elimination was used in combination with itself and Exploring ideas. For the most part, Elimination was utilised in a way that engaged the search for new ideas. This was achieved through exploring ideas and then eliminating them if they didn’t fit the
situation. It allowed the design to progress to a further stage. In this light, Elimination may be seen as a way forward towards a final solution.

Exploring Ideas was used with all the categories. However, the way in which Exploring Ideas was used in conjunction with the other problem-finding categories indicated that the interaction of these categories, even in the slightest way, was important to solving design problems. The use of Exploring Ideas with other categories allowed the problem solver to make a decision as to whether to persist with an idea or to forget about it.

Lack of knowledge was used mainly in combination with Exploring Ideas and itself. The way in which it was utilised varied among the subjects. The less experienced subjects tended to acknowledge their Lack of Knowledge but persisted by trying to find a solution. The more experienced understood that a lack of technical knowledge should not be an issue or could be corrected later, and then continued on with other parts of the design.

In summary the findings show that the combination of problem-finding categories played an important role in the designing process for the subjects studied. The categories of problem-finding seemed to fall into two different groups as described in Chapter 2. The first kind of problem-finding was when a person discovered something in their design that would not work or was unsure how to make it work. The second kind was when a person created a useful situation that facilitated the design process by raising new questions for inquiry. The results of this study indicate that Clarification, Exploring Ideas, Lack of Knowledge and Elimination occurred in both forms. The important issue here is that the role the problem-finding category played was dependent on the expertise and experience of the designer.
In conclusion, the findings of this study are fourfold. Firstly, the study showed that problem-finding was used throughout the design process and not solely at the initial problem-solving stage as had been generally accepted by the literature. Secondly, the study also identified and provided support for four types of problem-finding categories used in industrial designing. They are Clarification, Elimination, Exploring Ideas and Lack of Knowledge. Thirdly, the study showed how each of these categories played an important role in reaching a solution to a design. This was predominantly achieved through interaction between the categories. Lastly, the study showed that problem-finding ability was dependent on the expertise of the persons involved. The higher the level of expertise, the more able each was to use problem-finding effectively to solve the design problem.

**Contributions of the study**

This section outlines how the study contributes to the body of knowledge on problem-finding in design. Each contribution to knowledge is discussed separately in the following section.

Firstly, few studies had been undertaken on problem-finding especially in the area of industrial design. Of these, Getzels and Csikszentmihalyi’s (1976) longitudinal study on problem-finding was the most comprehensive and focused, although, it concentrated on a largely restrained definition of problem-finding in the fine arts. While there have been briefer studies on problem-finding undertaken (for example, Michael 1977; Dillon 1982) none have been in the area of industrial design, and none has investigated problem-finding in the light of the definition given in Chapter 2. While other studies have looked at problem-finding as the initial identification of a problem to be solved,
this study has conceptualised and examined problem-finding in four discrete categories. This approach is also distinctive in grounding the final selection of categories of problem-finding within the data collected from the subjects studied. That is, the categories were developed from both theoretical models (such as, Fink, Ward and Smith 1992; and Yashin-Shaw 2001) and also derived from the verbal protocols of the subjects, generating new and as yet unreported categories of problem-finding.

Secondly, the concept of problem-finding as defined in this study represents a contribution to the research on creativity. Getzels and Csikszentmihalyi’s (1976) study acknowledged that problem-finding ability was a predictor of creativity. Hence, through the association of problem-finding with creativity, the study addresses the question of the nature of links between problem-finding and creativity. This is achieved through the identification of the problem-finding categories as well as the exploration of problem-finding in this study.

Thirdly, this study has presented a comprehensive analysis of the role of problem-finding and how it is used to solve a problem. Although problem-solving models such as Middleton’s (1998) give some insight into the structure of ill-defined design problems, this study has given a clearer picture of the processes required to move through the model from the Problem Zone to the Satisficing Zone. This has been achieved in this study through the analysis of how different categories of problem-finding interact and combine with each other to reach a solution.

Lastly, this thesis has collected and analysed data in such a way that future data can be compared with it. For example, the empirical data on the interaction of problem-finding categories (Chapter 4) provides a basis against which future performance can be
evaluated. That is, such information can provide a yardstick that other studies in problem-finding may use for comparisons.

**Practical applications of the study**

The results of this study have some important implications for practitioners, teachers and students of industrial design. One of the aims of this study was to identify techniques that would enable people to become better designers. To some extent this has been achieved through the identification and categorising of problem-finding in this study.

By being able to identify what problem-finding is, and also when it is occurring, designers may begin to look for problem-finding when they design. An awareness of its existence may lead designers to think more metacognitively about their designs and to be pro-active in making decisions regarding possible solutions to a design problem. This may enable designers to become more self-checking and better able to understand the cognitive processes they are using when they design.

The four-fold categorisation of problem-finding may facilitate better ways of teaching design. It may enable teachers to explain what each category is and does. This in turn may lead to better teaching practices in design. For example, it may be possible to have design students verbalise the solving of a problem to a classmate. It would be the partner’s task is to identify when each kind of problem-finding is being used. This could be looked at in light of the results of this study and possible alternative design methods investigated. The student may be able to learn how to use problem-finding and tailor the problem-finding process to suit their particular ability. If students can understand firstly, what problem-finding is, secondly how to identify problem-finding, and lastly how it
can be used, then students of design may be able to produce more creative designs more easily.

As noted above, the teaching and learning of design may develop to include metacognitive awareness strategies. That is, the design students would be thinking about the strategies they use to solve the design, monitoring their use and controlling their effectiveness. This is in contrast to many current practices employed which use a trial and error method, but do not encourage metacognition. It is believed that if teachers and students use problem-finding as another tool to solve design problems the resulting solutions may be more effectively reached.

Understanding the role that problem-finding plays in solving design problems is important. This is because the techniques used by more experienced designers differ from those used by beginners. It may be possible to teach less experienced designers some of the more efficient problem-finding strategies used by those with more experience.

**Further research**

This study has revealed the need for additional research into problem-finding, which would build on this study. Firstly, it would be beneficial to undertake research, which would show to what extent the teaching of problem-finding enhances creativity in industrial designers. This could entail a comprehensive analysis of subjects over a longer period of time to allow for the learning to be effectively administered and monitored. Conducting such a study would give a more comprehensive understanding about the development of problem-finding ability as well as the contribution problem-finding has to creativity.
Secondly, this study collected data from four participants with varying degrees of expertise. It would be useful to conduct further research using subjects of the same level of expertise. This would strengthen the tentative findings about problem-finding categories and the roles they play in designing.

Thirdly, in addition to industrial designing the notion of problem-finding, as put forward by this study, could be examined in other areas. These could include, for example, town planning, fashion designing, writing and computer network design. By studying problem-finding in different disciplines other problem-finding categories may emerge and alternative and more powerful problem-solving tools can be developed.

Fourthly, current trends for studying designers is often focussed on a team or group work (Sivaloganthan, et al, 2000). It would therefore be useful to undertake this study with a socio-cultural diverse group and to identify if any differences exist in the thinking processes of individuals when compared to a group or even individuals within a group.

In summary, further research could be focussed on the effectiveness of teaching problem-finding to people with the same level of expertise but in different disciplines and from different socio-cultural backgrounds. Such studies would augment the findings of this study and would add to the limited body of knowledge on problem-finding.
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