Identifying the factors that impact on the problem solving performance of engineers

A thesis submitted for the degree of Doctor of Philosophy

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I, Jennifer Meiliana Harlim, certify that:

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d) any editorial work, paid or unpaid, carried out by a third party is acknowledged;

e) ethics procedures and guidelines have been followed.

Jennifer Meiliana Harlim
17 December 2012
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## Contents

Declaration................................................................................................................................. i
Acknowledgements.................................................................................................................. ii
Contents.................................................................................................................................. iii
List of Figures.......................................................................................................................... v
List of Tables............................................................................................................................ vii
Publications during Candidature............................................................................................. ix
Abstract..................................................................................................................................... 1
Chapter 1: Introduction............................................................................................................. 4
  1.1 Context and research rationale......................................................................................... 4
  1.2 Research objectives and questions ................................................................................. 5
  1.3 Thesis outline................................................................................................................... 6
Chapter 2: Literature Review.................................................................................................... 8
  2.1 Engineering problem solving ......................................................................................... 8
  2.2 Theory of Human Problem Solving .............................................................................. 10
  2.3 Transferability............................................................................................................... 12
  2.4 Problem solving heuristics ............................................................................................ 13
  2.5 Definitions of good problem solvers............................................................................ 14
  2.6 Beyond skills.................................................................................................................. 15
  2.7 Measurement of problem solving performance ............................................................ 16
  2.8 What is learned from existing literature?...................................................................... 20
Chapter 3: Methodology.......................................................................................................... 22
  3.1 Mixed methods.............................................................................................................. 22
  3.2 Sampling and ethical considerations.............................................................................. 24
  3.3 Phase 1: Grounded Theory............................................................................................ 26
  3.4 Phase 1: Repertory Grid Technique............................................................................... 30
  3.5 Phase 2: Online survey.................................................................................................. 35
  3.6 Establishing rigour and validity .................................................................................... 40
Chapter 4: Findings.................................................................................................................. 42
  4.1 Introduction..................................................................................................................... 42
  4.2 Understanding the problem: the key to good problem solving..................................... 42
    4.2.1 Results .................................................................................................................... 42
    4.2.2 Discussion .............................................................................................................. 46
  4.3 Quickness in problem solving, expertise and impact of assumptions............................ 48
    4.3.1 Results .................................................................................................................... 48
List of Figures

Figure 3.1: Data triangulation ................................................................. 23
Figure 3.2: Research design ............................................................... 24
Figure 3.3: Data collection and data analysis process ......................... 27
Figure 3.4: Summary of the process used with the grounded theory data collection and analysis .................................................. 30
Figure 3.5: Data elicitation in the RGT process .................................... 31
Figure 3.6: Ideal triadic comparisons .................................................. 32
Figure 3.7: Triadic comparisons generated by Idiogrid when the three questions were included ................................................... 33
Figure 3.8: Summary of the RGT process .............................................. 34
Figure 3.9: Development of survey questions ...................................... 35
Figure 3.10: Survey development process .......................................... 36
Figure 3.11: Demographics of the engineers who responded the question pertaining to their profession status ....................................... 37
Figure 3.12: Demographics of the engineers who responded to the question pertaining to the field that they are currently in .................. 38
Figure 3.13: Demographics of the engineers who responded to the question pertaining to their age .................................................. 38
Figure 3.14: Demographics of the engineers who responded the question pertaining to their gender .......................................... 39
Figure 3.15: Demographics of the engineers who responded to the question pertaining to their industry experience ...................... 40
Figure 4.1: Summary of themes identified in the study ......................... 42
Figure 4.2: The importance of understanding the problem theme and examples of quotes from participants ........................................ 43
Figure 4.3: Holistic problem solving theme and examples of quotes from participants ................................................................. 44
Figure 4.4: Understanding the problem is the key to good problem solving ...... 48
Figure 4.5: The spread of responses on how much time is spent on understanding the problem according to the different groups of engineers ........................................... 53
Figure 4.6: The spread of responses on how much time is spent on the planning stage according to the different groups of engineers ........................................... 54
Figure 4.7: The spread of responses on how much time is spent on the implementation stage according to the different groups of engineers ............... 55
Figure 4.8: The effect of assumptions in problem analysis theme and examples of quotes from participants ........................................ 57
Figure 4.9: Impact of assumptions and expertise on understanding the problem..... 63
Figure 4.10: Challenging understanding theme and examples of quotes from participants ................................................................. 69
Figure 4.11: Detrimental effect of “options” theme and examples of quotes from participants................................................................. 71

Figure 4.12: Role of self-efficacy in transferability theme and examples of quotes from participants................................................................. 74

Figure 4.13: Evaluation and reflection cycle in the perspective of young engineers in the research ............................................................................. 77

Figure 4.14: Evaluation and reflection cycle in the perspective of senior engineers in the research ............................................................................. 78

Figure 4.15: Impact of strategies (evaluation and reflection) and personal qualities (self-efficacy) on performance and transfer ................................................ 83

Figure 4.16: The value of working with others ................................................................. 93

Figure 4.17: Strategies and personal qualities that assist with overcoming assumptions that impact on the understanding of the problem ...................... 95

Figure 5.1: Problem solving and transferability model proposed in this study ........ 97

Figure 5.2: Two approaches of evaluation and reflection............................................... 99

Figure 5.3: Two approaches to the role of peers ........................................................... 99
List of Tables

Table 2.1: Two broad categories of transfer ........................................................... 13
Table 2.2: Problem solving heuristics .................................................................... 14
Table 2.3: Summary of problem solving evaluations by engineering educators ...... 19
Table 3.1: Participants’ demographics in Phase 1 ................................................... 28
Table 3.2: Summary of trustworthiness criteria used in this study ......................... 41
Table 4.1: Understanding the problem theme in RGT data set ............................. 43
Table 4.2: The need of methods/tools theme in RGT data set ............................. 45
Table 4.3: Understanding the problem in survey data set ..................................... 46
Table 4.4: Summary of different opinions between the novice and the expert on quickness ........................................................... 51
Table 4.5: Time allocated by engineers in the survey to different stages of the problem solving process ........................................................... 52
Table 4.6: Statistical analysis on group comparisons of time spent on understanding the problem ........................................................... 56
Table 4.7: Survey response on expertise and novel problems .............................. 58
Table 4.8: Survey responses on expertise and novel problems broken down into groups according to industry experience ................................. 59
Table 4.9: Dual concepts of the value of prior experience and expertise in the RGT result ........................................................... 59
Table 4.10: Themes of evaluation and reflection from RGT data .......................... 64
Table 4.11: Summary of differences of opinions on the theme of evaluation and reflection between novice and expert engineers in the study ... 66
Table 4.12: Survey responses on engineers and the evaluation process ............... 66
Table 4.13: Survey responses of engineers and the evaluation process broken down into groups based on industry experience ................................. 67
Table 4.14: Survey responses on the development of problem solving skills through formal education ........................................................... 68
Table 4.15: Survey responses on the development of problem solving skills through industry experience ........................................................... 68
Table 4.16: Survey responses on active learning and problem solving ................ 73
Table 4.17: Self-efficacy theme in RGT data ........................................................... 76
Table 4.18: The role of peers in the RGT result ..................................................... 85
Table 4.19: Survey responses on the importance of involving others during problem solving ........................................................... 85
Table 4.20: Survey responses on understanding different perspectives of a problem through discussions with others ........................................ 86
Table 4.21: Summary of the difference of opinions between novice and expert engineers on the role of peers when resolving problems ................. 87
Table 4.22: Survey response on when other people should be involved when resolving problems .......................................................... 88
Table 4.23: Statistical analysis on group comparisons on when other people should be involved when resolving problems ................................................. 89
Table 4.24: Open-minded theme raised in the RGT data ................................................. 90
Table 4.25: Survey responses on the impact of expertise on creativity ................. 91
Publications during Candidature


Abstract

The aim of higher education institutions is to design effective courses that are of relevance and enhance students’ employability. Among the many attributes that higher education students are expected to develop are problem solving skills. Despite attempts to cultivate problem solving skills, an accurate means of measuring problem solving performance is yet to be developed.

The purpose of this study is three-fold:

1. To understand the problem solving process better from the perspective of engineers.
2. To identify what factors impact on problem solving performance with transferability into new problems being taken into account.
3. To identify a set of factors that can be developed as standards for measuring problem solving performance.

The following research questions were investigated:

- What do engineers perceive to be aspects of good problem solving?
- What factors are the most vital for problem solving performance and transferability?

This study utilised a mixed methods approach using both qualitative and quantitative methods. Data collection was carried out in two phases:

- The first phase is the qualitative part of the research design. In this phase, Grounded Theory and Repertory Grid Technique (RGT) were used to collect data. This part of the study was carried out between August 2009 and February 2011, involving 22 engineers.
- Upon completion of the analysis of data from Phase 1, Phase 2 which was the quantitative part of the research was commenced. Data collection via an online survey was carried out between 29 March 2012 and 16 June 2012. This phase involved the responses from 273 engineers.

The three sets of data from Grounded Theory, RGT and online survey were then triangulated to ensure validity and robustness. Further strategies to ensure validity and robustness were also employed in this study.
The six key findings of the study are:

1. The key to good engineering problem solving is the ability to understand the problem fully before resolving it.
2. There is a misconception that quick problem solving is good problem solving, especially in the opinions of young engineers.
3. Expertise may have adverse impact on problem solving performance, especially for novel problems.
4. Specific strategies that minimise the effect of personal assumptions are helpful when facing new problems; they involve the role of peers, and evaluation and reflection.
5. Personal qualities that impact on performance and transferability are open-mindedness and self-efficacy.
6. “Options” impact on the transfer of problem solving ability. “Options” are conditions that enable the problem solver to resolve problems quickly without understanding the rationale of the solution and reduce the problem solver’s need to evaluate personal assumptions and knowledge (e.g., relying on help from others).

The six key findings have implications for practice. The design of formal engineering education should take into account the following:

- The course should improve students’ ability to understand problems. Therefore, training should focus on strategies and tools that assist with problem analysis.
- Young engineers should be trained to develop the habit of evaluating and reflecting.
- The course should address misconceptions such as quickness in problem solving and the focus on solutions.
- “Options” should be minimised.
- The course design needs to take into consideration how open-mindedness and self-efficacy can be enhanced.
- Continuous training even for experts needs to be considered.

To effectively evaluate problem solving courses, the following factors are recommended as indicators of performance and possible transfer:

- ability to understand the problem well (cognitive skill)
- open-mindedness (non-cognitive factor)
self-efficacy (non-cognitive factor)

The findings in the research contribute to existing literature in the following ways:

- A better understanding of the problem solving process – exploration of what, how and why.
- The discovery that factors influencing performance are linked and not independent of each other.
- Identification of the factors that truly impact on performance.
- Identification of the factors that have a detrimental effect on performance and transferability.

As this research yields rich and in-depth data, further analysis of the data collected could be carried out for future research direction. These data may provide additional useful information pertaining to engineering education in general. Future research is also required to test the findings of this study in experimental settings and in a bigger population sample. A future study that investigates how the recommendations proposed in this research should be carried out. Findings in this thesis can also lead to the development of a proper evaluation tool to measure the effectiveness of problem solving courses.
Chapter 1: Introduction

1.1 Context and research rationale

The aim of higher education institutions is to design effective courses that are of relevance and enhance students’ employability. A review of the Australian higher education system highlighted that preparing students with “skills of critical analysis and independent thought” (Bradley, Noonan, Nugent, & Scales, 2008, p. 5) is crucial. In addition, a focus on graduate attributes has emerged in recent literature. Among the many attributes that higher education students are expected to develop are problem solving skills (Hambur, Rowe, & Luc, 2002).

The focus of engineering education is the development of engineers’ ability to solve problems (Beder, 1999; Roth, 2007). This is one of the unique aspects of engineering education as it increases the opportunity for a wider career pathway for the engineer. Beder (1999) cited that some engineers are able to cross into other professions because of their problem solving ability. Therefore, it is imperative to investigate how problem solving performance can be enhanced through formal instructions.

More often than not, strategies used to develop problem solving courses are grounded in the assumptions that expertise ensures better performance. Hence, much of the focus of training is on developing novice engineers into experts in their field through specific tools and heuristics. Moreover, much of the research in problem solving focuses on a specific field and definite problems. Engineering problem solving requires the engineer to be able to cope with complex problems and often with problems that require knowledge from outside their own field. Current literature on problem solving does not fully represent problem solving in a semantically rich domain such as engineering. Designing courses based on these literature may not sufficiently cover the requirements that an engineer needs to effectively resolve problems once he or she enters the industry.

The importance of problem solving skills is also highlighted in literature (Adams, Kaczmarczyk, Picton, & Demian, 2010; Belski, 2009; Carr, 1990; Cotton, 1991; Kalyuga, Renkl, & Paas, 2010; Kerka, 1992; Prawat, 1991; van Gelder, 2001, 2005; Wilson, 2000). However, despite attempts to cultivate problem solving skills, an accurate measuring system for problem solving performance is lacking (Belski, 2009;
Borgianni, Cascini, & Rotini, 2011; Hambur, et al., 2002; Litzinger, Lattuca, Hadgraft, & Newstetter, 2011). Given the complexities of factors that are involved in problem solving, engineering educators are evaluating their courses according to their own interpretation.

It is important to understand the problem solving process from the perspective of the engineers. It is also crucial to discover problem solving factors that can be used to develop a proper measurement tool for effective learning. This research takes the perspective that problems by nature are new situations. For successful performance in problem solving, a degree of learning transferability from a previously faced problem is required. Therefore, this research focuses on the investigation of factors that impact on performance in complex and new problems.

1.2 Research objectives and questions

The purpose of this research is to address the following:

1. To understand the problem solving process better from the perspective of engineers.

2. To identify what factors impact on problem solving performance with transferability into new problems being taken into account.

3. To identify a set of factors that can be developed as standards for measuring problem solving performance.

This research investigates the following questions:

- What do engineers perceive to be aspects of good problem solving?

- What factors are the most vital for problem solving performance and transferability?
1.3 Thesis outline

This thesis is divided into six chapters, including the introductory chapter. The following chapters are:

Chapter 2: Literature Review
This chapter covers literature on problem solving and transferability. Engineering problems are defined in this chapter based on the literature. The literature discussed includes Theory of Human Problem Solving, Theory of Transfer, problem solving heuristics, the current known factors of problem solving performance and how problem solving is currently measured in practice. The gaps in the literature review are discussed and the purpose of the research is clarified. The chapter ends with a reiteration of the research questions. As this study deals with concepts relating to theories, it is not possible to only include references from the last 5–10 years. Much of the research in problem solving flourished in the 1970s and 1980s. These studies formed the basis of what is currently known and practised in engineering education and thus cannot be disregarded.

Chapter 3: Methodology
This chapter explains the methodology used. Mixed methods (Grounded Theory, Repertory Grid Technique [RGT] and Survey) are discussed and the design of the data collection is explained. Specific details on how each method was carried out to collect and analyse data are included. A discussion on sampling and ethical considerations is also included. Challenges faced during the data collection process are also stated. The chapter concludes with a summary of the strategies utilised to ensure the validity and robustness of the findings.

Chapter 4: Findings
The findings are presented in this chapter. Themes are categorised and are compared to the RGT and survey data. Each result section is followed by a discussion. The discussion of findings also covers a comparison with the existing literature. At the end of each section, a model is built based on the findings. The chapter concludes with a summary of the six key findings of this study.
Chapter 5: Model and Recommendations
This chapter discusses in depth the model of problem solving that has been developed. The implications for practice are stated and recommendations are made.

Chapter 6: Conclusion and Future Research
The concluding chapter summarises the key findings in relation to the research questions. This chapter also covers the implications of the findings for problem solving theory. The research limitations and possible future research directions are also discussed in this chapter.
Chapter 2: Literature Review

2.1 Engineering problem solving

Robertson (2001) posited that a problem starts with a goal. However, the situation becomes a problem when the steps required to achieve that goal are not known (Robertson, 2001). This definition was supported by Chi and Glaser (1985). Carlson and Bloom (2005) proposed that when an individual faces a situation which he or she does not know how to deal with, then it can be classified that the person is facing a problem. Yeap (1998) supported this by proposing that a problem is a situation where the resolution is not obvious. Tallman and Gray (1990) suggested that problems are defined as non-routine events. In essence, a problem arises due to an unknown or novel situation that a person faces. For the purpose of this study, a problem is defined as an unusual situation that a person faces where an acceptable solution may not be immediately evident. The nature of a problem itself requires the problem solver to cope with uncertainties.

Traditionally, engineering problems are perceived as well-defined problems with definite solutions. For this reason, much of engineering education is focused on technical aspects such as science and mathematics (Dym, Agogino, Eris, Frey, & Leifer, 2005; Roth, 2007). However, research by Jonassen, Strobel and Lee (2006) and Beder (1999) identified that problems faced by engineers in the real workplace differ significantly from those presented in a university setting. It was found that the problems faced by engineers in the industry are often ill-structured and seldom with exact solutions (Jonassen, 1997; Jonassen, et al., 2006). Ill-defined problems can be categorised as problems that have the following characteristics (Jonassen & Hung, 2008):

1. Not all the problem parameters are known.
2. The problem can be interpreted in many possible ways.
3. Interdisciplinary knowledge is required to resolve the problem.
4. Possible solution/s may impact other parts of the system being considered.
5. The problem can be resolved by many solution paths.

It can be proposed that engineering problems are complex. According to Jonassen and Hung (2008), the complexity of a problem is determined by the following:

- The breath of knowledge required to resolve the problem.
• The difficulty level of comprehending and applying the concepts involved in the problem.
• The skill and knowledge levels required to resolve the problem.
• The degree of non-linearity of the relations among the variables within the problem space.

Recent literature on engineering education has suggested that engineering problem solving is design thinking (Dym, et al., 2005; Luebbe, Weske, Edelman, Steinert, & Leifer, 2010). “Design thinking” is defined as the integration of knowledge that combines both theory and practice to resolve ill-structured and complex problems (Buchanan, 1992; Dorst, 2011). The concept of design thinking suggests that innovation and creativity are required (Brown, 2008). Amabile (1983) supported the concept that problem solving is not distinct from innovation and creativity. Innovation refers to something that is new or significantly improved and should add value to the existing system (Baregheh, Rowley, & Sambrook, 2009; Rogers, 1998). Brown (2008) suggested that “innovation is powered by thorough understanding, through direct observation of what people want and need in their lives”. (p. 1). He stressed that design thinking is human-centric problem solving. This idea is aligned with the expectation that in their profession, engineers resolve problems to improve the lives of people (Beder, 1999; English, 2008; Grasso, Callahan, & Doucett, 2004; Kurfess, 2003; McCarthy, 2009; Roth, 2007).

Creativity is the creation of something new and of value (Aldous, 2007; Villalba, 2008). Adams (2010) found that the term “creativity” was perceived in two ways by the engineers in his research: either (1) creating an aesthetically pleasing product or (2) applying improvements to existing systems (solutions or processes). It can be proposed that the latter description fits better within the engineering context. Buchanan (1992) also believed that design in the technical field is not directed towards creating completely new solutions, but focuses on solutions that in some sense are already known through systematic and analytical processes.

The definition of design thinking most importantly suggests that problem solving in engineering is inherently linked to the process of thinking. The terms “problem solving” and “thinking skills” are interchangeable, as highlighted by Cotton (1991). Belski and Belski (2008) reinforced this by positing that problem solving engages the mind in generating new ideas to resolve problems. There is recognition in the
literature that meta-skills are crucial to problem solving performance (Brandsford, Sherwood, Vye, & Reiser, 1986; Mayer, 1998; Yeap, 1998).

It can then be concluded that engineering problem solving can be defined as:

1. Dealing with complex problems.
2. Dealing with uncertainty.
3. Linked to the greater good (human factors are involved).
4. Requiring extensive interdisciplinary knowledge.
5. Requiring innovation and creativity.
6. Not separate from the act of thinking.

2.2 Theory of Human Problem Solving

In discussing problem solving performance, it is important to acknowledge the Theory of Human Problem Solving. This theory was developed from the work of Newell and Simon (1972) in Artificial Intelligence (AI) and provided the basis of much problem solving research.

The theory suggests that the human brain functions like an information processing system. The theory posits that problem solving involves cognitive processes that transform a problem state to reach a goal state (Chi & Glaser, 1985; Newell & Simon, 1972). In particular, structured knowledge or schemata assist problem solving (Gick, 1986). Hardin (2002) proposed that “facts unite to form concepts, concepts join to form rules, and rules join to form problem solving structures” (p. 229).

Newell and Simon (1972) suggested that “when a problem is first presented, it must be recognised and understood” (p. 809). Newell and Simon (1972) believed that problem solving relies on pattern recognition. This theory relies heavily on the concept of the accumulation of knowledge and developing expertise. It suggests that prior experience and expertise contribute to better problem solving performance.

The implication of this is that there is an assumption that when a novice behaves like an expert when solving a problem, he or she has truly become a good problem solver. It is no surprise that the problem solving behaviour of experts is usually considered to be the benchmark for “goodness”. This assumption has led to research focusing on expert problem solving (Atman, Chimka, Bursic, & Nachtmann, 1999; Bilalic, McLeod, & Gobet, 2009; Carlson & Bloom, 2005; Chi, Glaser, & Rees, 1982; Gick, 1986;
Research by Bilalic et al. (2009), Chi et al. (1982) and Gick (1986) investigated how novices and experts resolve problems. Their aim was to identify the different problem solving strategies adopted by these two groups. It was found that novice problem solvers use a “working-backward” strategy while experts use a “working-forward” strategy when resolving problems (Chi, et al., 1982; Gick, 1986). In a “working-backward” strategy, the problem solver tries to resolve problems by identifying the goal to be achieved and working backwards from that goal to work out what should be done. On the other hand, a “working-forward” strategy requires the problem solver to work out what information is given and what is unknown until the solution is known.

Carlson and Bloom (2005) looked at the problem solving heuristics used by experts. They discovered that expert problem solvers use cyclic heuristics (refer to Section 2.4 for more details). Research by Atman et al. (1999) and Gobet and Simon (1996) found evidence that experienced problem solvers tend to perform better than those who are less experienced. These studies supported the work of Newell and Simon (1972) and proved that experience and expertise have a significant impact on a person’s ability to solve problems well.

However, it was observed that the definition of expertise varies in the abovementioned studies. “An expert” is defined as a person with more than 10 years experience in his or her field (Chase & Simon 1973; Prietula & Simon 1989). Yet this definition of expertise is not strictly followed in the abovementioned studies. For example, Atman et al. (1999) compared the performance of senior versus first year students. Carlson and Bloom (2005) considered PhD graduates to be experts.

There is no doubt that these studies have contributed to the design of problem solving courses. For example, Litzinger et al. (2011) implemented strategies that assist the development of expertise in their course. In addition, there has been an emphasis on teaching novices the problem solving heuristics used by experts, with the hope that this would improve performance. The specific heuristics are discussed in Section 2.4.

Most of the studies in expert problem solving performance have investigated the performance in one specific field – mathematics, physics or chess. It is worthwhile to consider the question: If an expert in a particular field faces a completely new problem beyond his or her domain of expertise, how would prior experience
contribute to his or her problem solving ability? This is particularly important as engineering problem solving requires extensive knowledge even beyond engineers’ domain of expertise (see Section 2.1). Moreover, problems by nature are new situations not experienced before, as suggested in Section 2.1.

The theory of human problem solving and the subsequent literature that built on this theory did not take transferability into consideration. There is a gap between the current knowledge of problem solving performance and its transfer. The next section discusses the Theory of Transferability.

2.3 Transferability

It is not possible to separate learning from transfer. Effective learning should result in meaningful learning (Singley & Anderson, 1989). Therefore, the goal of learning should be transferability (Macaulay, 2000; Marini & Genereux, 1995; Perkins & Salomon, 1992). Singley and Anderson (1989) argued that “for education to be effective, curricula must be designed with an eye toward transfer” (p. 2). Transfer is defined as the application of knowledge obtained from one situation to other situations (Singley & Anderson, 1989). This definition was supported by Phye (2001) who argued that a learner must be able to apply their acquired knowledge to new problems.

However, evidence in the literature suggests that this is rarely the case (Atman et al., 2010; Carr, 1990; Marini & Genereux, 1995; Perkins & Salomon, 1992; van Gelder, 2001). It has been found that, in general, “skills acquired in one domain or context often do not carry over to other situations” (van Gelder 2001, p. 2). This finding was supported by Carr (1990), who believed “that students are lagging in problem solving and thinking skills is apparent at all levels of education”. It was found that while students were able to improve their problem solving skills in relation to the course they were taking, whether or not they were able to improve their skills in other situations were not measured. Unless proper measurement is possible, an improvement in overall problem solving skills cannot be inferred from an improved outcome in one single problem solving course.

Studies of transferability have identified two main type of transfer, as shown in Table 2.1.
Table 2.1: Two broad categories of transfer

<table>
<thead>
<tr>
<th>Direct transfer</th>
<th>Indirect transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near</td>
<td>Far</td>
</tr>
<tr>
<td>Vertical</td>
<td>Lateral</td>
</tr>
<tr>
<td>Specific</td>
<td>Non-specific</td>
</tr>
<tr>
<td>Literal</td>
<td>Figural</td>
</tr>
</tbody>
</table>

Summarised from (Kirwan, 2009; Perkins & Salomon, 1992; Royer, 1979; Singley & Anderson, 1989).

“Direct transfer”, which includes near, vertical, specific and literal, refers to the ability to apply procedures and knowledge to a problem with a similar context and/or complexity to a problem previously faced (Perkins & Salomon, 1992; Royer, 1979; Singley & Anderson, 1989). On the other hand, “indirect transfer” is the ability to apply procedures and knowledge to a problem that differs significantly in terms of context and/or complexity to a problem previously faced. Indirect transfer is required when the problem parameter is significantly changed and a shift of knowledge may be required. While all types of transfer are important, the theories mentioned above indicate that indirect transfer should be the aim of education. Royer (1979) argued that when skills and knowledge are transferred to the real world, the transfer usually occurs in an indirect manner. In addition, as discussed in Section 2.1, the nature of engineering problems requires the problem solver to deal with new situations. Thus, transfer must be taken into account when considering training for improved performance in engineering design tasks.

### 2.4 Problem solving heuristics

Studies on how experts resolve problems (as discussed in Section 2.2) led to the development of problem solving heuristics. One of the key defining models on problem solving heuristics was developed by Polya (1945) in his work on mathematics problem solving. Carlson and Bloom (2005) extended Polya’s model and discovered that the four-step problem solving process is cyclic. In observing the expert subjects in their study, they found that experts engage in trial and error, oscillating between steps 2 and 4, until the solution is established. Specific to engineering, Belski (2002) proposed a seven-step heuristics based on Systemic
Thinking. This set of heuristics takes into account the complexities of engineering design tasks. Belski (2002) also believed that these heuristics are inter-connected.

Despite the differences in the models, it can be summarised that problem solving requires a number of key steps: (1) understanding the problem, (2) planning, (3) implementation and (4) evaluation. A summary of the problem solving heuristics discussed above is presented in Table 2.2.

Table 2.2: Problem solving heuristics

<table>
<thead>
<tr>
<th></th>
<th>(Polya, 1945)</th>
<th>(Carlson &amp; Bloom, 2005)</th>
<th>(Belski, 2002)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understanding the problem</td>
<td>1) Understanding the problem</td>
<td>1) Orienting: sense making, organising, constructing</td>
<td>1) Situation analysis</td>
</tr>
<tr>
<td>Planning</td>
<td>2) Developing a plan</td>
<td>2) Planning: conjecturing, imagining, evaluating</td>
<td>2) Revealing the system’s stage of development</td>
</tr>
<tr>
<td>Implementation</td>
<td>3) Carrying out the plan</td>
<td>3) Executing: computing, constructing</td>
<td>3) Identifying an ideal solution</td>
</tr>
<tr>
<td>Evaluation</td>
<td>4) Looking back</td>
<td>4) Checking: verifying, decision making*</td>
<td>4) Idea generation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5) Failure prevention</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6) Adjusting the super-system and sub-systems in accordance with the solution found</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7) Reflection on the solution and the process of the solution</td>
</tr>
</tbody>
</table>

* If solution is inaccurate, then return to stage 2.

2.5 Definitions of good problem solvers

Given the extensive focus on studies that have investigated how expert resolve problems, it is not surprising that the definition of a good problem solver relies on the heuristics discussed in the previous section. It is expected that good problem solvers possess the skills to effectively carry out the four problem solving procedures. Good problem solvers are expected to possess well-developed abilities to identify and
analyse a problem, select and organise relevant information, represent the problem, translate relevant information towards finding a solution, identify one or more solution strategies, and apply and evaluate these strategies (Hambur, et al., 2002).

Specifically for engineers, Engineers Australia (2009) suggested that engineers:
- have the ability to identify the technical nature of the problem, achieve a solution and evaluate the impact of the solution on the system;
- have the ability to cope with ambiguity, have creativity and can see the links between other disciplines and engineering.

The definition proposed above does not only take into account the skills required to carry out engineering tasks. Engineers Australia (2009) also took into account that certain personal qualities are required for engineers to cope with engineering problems.

2.6 Beyond skills

Brodie and Brodie (2009) acknowledged that engineering is “predominantly a knowledge-based industry” (p. 137), where information is a commodity. It is of no surprise that the focus of engineering education relies heavily on the dissemination of engineering knowledge. Prawat (1991) argued that teaching methods that rely on idea generation are an effective way of teaching problem solving and thinking skills. Considering that “ideas function like perceptual schemata”, teaching thinking skills based on ideas will “allow individuals to extract new information from the environment while at the same time building upon existing knowledge” (Prawat, 1991, p. 6). The concept of building knowledge corresponds with the concept of schemata in the Theory of Human Problem Solving (see Section 2.2).

Recent research such as that of Goode and Beckmann (2010) has found evidence that having information impacts positively on problem solving performance. In their research, Adams et al. (2009) discovered that engineers utilise knowledge networking, as suggested by Allen and Long (2009). This idea recognises that when resolving engineering problems, knowledge gaps may exist. This concept also stresses the importance of communication skills for engineers. Hadgraft and Muir (2003) recognised that, other than specific sets of engineering skills and knowledge, graduating students should also have specific personal qualities. A focus on
developing communication and teamwork skills was also highlighted in their model (Hadgraft & Muir, 2003).

It is also recognised that qualities such as creativity, open-mindedness, motivation, taking risks and confidence can impact on problem solving performance (Adams, 2010; Adams, Kaczmarczyk, Picton, & Demian, 2009; Adams, et al., 2010). The importance of motivation for problem solving performance is also well documented (Dalrymple, Sears, & Evangelou, 2011; Mayer, 1998; Song & Grabowski, 2006).

These studies have demonstrated and reaffirmed that problem solving requires skills, knowledge and personal qualities. This confirms that problem solving is complex and is affected by various factors (English, 2008; Robertson, 2001). The complexities present another challenge for engineering educators: measuring problem solving performance.

### 2.7 Measurement of problem solving performance

In the previous sections on engineering problem solving, the theories underpinning human problem solving and transferability were discussed. Skills and other factors that impact on problem solving performance were identified through the literature explored. It is clear that these studies have informed the strategies used in the formal education of engineers. However, to ensure the effectiveness of these strategies, evaluation is paramount.

In her study of current practice of assessments in education, Nusche (2008) identified two broad categories of assessments: cognitive and non-cognitive. Cognitive outcomes refer to the acquisition of knowledge and skills. Non-cognitive outcomes refer to the development of personal attitudes and values. She suggested that direct assessments that focus on domain-specific knowledge and skills can be used as a measure of cognitive skills. On the other hand, surveys and questionnaires can be used in general to measure non-cognitive outcomes. While Nusche (2008) admitted that cognitive outcomes are easier to measure, she highlighted the importance of measuring both outcomes. In reviewing the practices in education in Australia, Brazil, Canada, Mexico, the UK and the USA, she observed that most assessment practice only makes use of one outcome or the other (Nusche, 2008).
Graduate Skills Assessment (GSA) (Hambur, et al., 2002) is a tool that was developed in Australia. GSA measures specific graduate attributes, including problem solving. The main focus of the problem solving component in this tool is to test the ability of students in carrying out the main steps of problem solving heuristics as described Section 2.4. It is assumed that the ability of students to perform well in this test is an indicator of required skills and transferability (Hambur, et al., 2002).

The problem solving component of the test uses 30-item multiple choice questions. The questions include general problems based on mathematics and puzzles. Wu (cited in Hambur, et al., 2002) criticised that the GSA component for problem solving does not take into account the cognitive processes that are involved in problem solving and that the types of problems given are not reflective of real problems. In addition, within GSA critical thinking, problem solving and inter-personal skills are classified as different dimensions, assessed by different tests. This is contradictory because, as established in Sections 2.1, 2.5 and 2.6, these dimensions form the overall problem solving capability.

Specific to engineering educators, Taraban, Craig and Anderson (2011) measured performance by going through students’ problem solving processes through the use of written assignments and think-aloud protocol. They coded the results as indicators of a mixture of higher-order and lower-order processes which they had established from previous literature of problem solving. Their categories included 10 strategies that could be displayed to indicate problem solving capability. The focus of this technique is to identify the problem solving process that the students used. However, the problems that were used were strongly mathematics/physics based and were not reflective of real-life engineering problems as identified in Section 2.1.

Belski’s (2009) research focused on the evaluation of a thinking and problem solving course which was devoted to the TRIZ problem solving method. Control groups were utilised. Feedback from the students was collected through a formal survey, Course Experience Surveys (CES), administered by the university. This formal survey included a specific question pertaining to problem solving. Responses to this question from the students who took the course were compared to CES feedback of other students in other courses. Additional pre-course and post-course surveys were conducted. Significant differences between students’ pre- and post-course opinions on their ability to solve problems were reported. However, Belski (2009) believed the improvement reported may not have reflected the true improvement in thinking and
problem solving as the data were collected solely through students’ opinions. Nonetheless, the use of formal university surveys to evaluate the effectiveness of courses is common. A similar survey was also used by Lindsay, Munt, Helen, Scott and Sullivan (2008) in their evaluation of the impact of their problem solving course on their students’ learning.

Sobek II and Jain (2004) used client satisfaction and the quality of the final designed product as measures of a good outcome. The assumption in this study was that a good process leads to a good outcome (Sobek II & Jain, 2004). Their investigation utilised open-ended problems. Sobek II and Jain (2004) developed a Client Satisfaction Questionnaire and a Design Quality Rubric to evaluate the effectiveness of the problem solving performance of the students involved in their course. Interestingly, the judgement of the outcome was based on the evaluations of the project clients and four engineering professionals. It can be argued that the interpretation of the results is subjective. In addition, Sobek and Jain (2004) explored the use of student journals and coded their entries as examples of skill application. Vidic (2010) also used students’ portfolios for assessment when investigating the demonstration of thinking and problem solving skills. Similarly to Belski (2009), Vidic (2010) used students’ self-assessments and a control group. Additional formal assessments of student presentations were also used as a measuring component of performance (Vidic, 2010). Formal assessment has frequently been used by other educators (Mourtos, Okamoto, & Rhree, 2004; Paton, 2010).

Borgianni, et al. (2011) evaluated the effectiveness of the TRIZ course through the use of case studies. They used case studies to evaluate the following criteria:

- the ability to follow a systematic problem solving process (similar to that which was taught in the course);
- the ability to describe factors or conditions beyond the problem context;
- the ability to describe factors or conditions that impact on the system;
- the ability to formalise the elements that ground contradiction.

They used six open-ended questions to investigate the capabilities in the above list. The scoring system was assigned on the prescribed quality of an answer, using different parameters. In addition, a control group was used as comparison.
Livotov (2011) evaluated the effectiveness of problem solving education in the professional context. Similarly to Belski (2009), he used pre-course and post-course measurements. However, Livotov’s (2011) method of evaluation attempted to quantify improvement, using a questionnaire covering the 10 main innovation and inventive skills covered by the course. At the beginning of the course, the engineers were asked to rate the importance of the skill and their evaluation of their current skill level. At the end of the course, the learners were asked to rate their evaluation of their changed performance. All these evaluations were then put through a formula devised by Livotov (2011) to calculate the growth of total skills performance and final total skills performance.

In summary, it was observed that while some common tools have been used by engineering educators, in general the way evaluation is carried out varies (summarised in Table 2.3). Despite engineering problem solving requiring skills, knowledge and personal qualities, as previously identified (Sections 2.1–2.6), it is obvious that engineering educators are unable to implement measures that take all these into account. Thus, educators have had to make their own judgements as to which factors are important and should thus be measured. Attempts have been made to measure specific skills, often informed by the suggestion of the skills that good problem solvers have, as discussed in Sections 2.4 and 2.5. Nonetheless, some educators have chosen to use only non-cognitive outcomes as indicators of the success of their courses.

<table>
<thead>
<tr>
<th>Direct evaluation</th>
<th>Indirect evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formal assessment</td>
<td>Non-formal assessment</td>
</tr>
<tr>
<td>Outcome based</td>
<td>Process based</td>
</tr>
</tbody>
</table>

Table 2.3: Summary of problem solving evaluations by engineering educators

The use of control groups when assessing the effectiveness of engineering education courses is a norm (Olds, Moskal, & Miller, 2005). The assumption with the use of control groups is that the students compared have similar characteristics such that
they are comparable (Olds, et al., 2005; Peng & Ziskin, 2008). However, Olson (2004) highlighted that perfectly controlled experimentation is not possible in educational research. The beliefs, goals and intention of each individual student may impact the experimentation outcome (Olson, 2004). Unsystematic variation which resulted from random factors such as natural differences in students’ ability, or even the time of day needs to be overcome for accurate measurement (Field, 2009). For effective research outcome, the use of control groups should be randomised. However, difficulties such as selection bias which impacts achieving true randomised groups in educational setting is well documented (Olson, 2004; Slavin, 2002). Olson (2004) also highlighted the difficulty in completely segregating the experimental and the control groups in education.

In addition, while the use of control groups may give insights into overall group performance, it does not take into account the impact of a course on the individual. Pre-course and post-course testing provides a better alternative for evaluating the impact of a course on individual students’ problem solving abilities. However, as previously mentioned in Section 2.2, current measurements do not take transferability into account. As observed in the way that engineering educators evaluate problem solving skills, longitudinal studies are rarely carried out. This is perhaps due to the limitations of the academic setting. However, this is a justification for the development of better instruments to predict transferability.

In summary, it is evident is that there is no standard in the way engineering educators evaluate the effectiveness of their courses. It is clear that this process is dependent on the interpretation of the engineering educators.

2.8 What is learned from existing literature?

As summarised in Section 2.1, engineering problem solving is complex and requires the engineer to deal with uncertainty. Engineering problem solving is comparable to engineering design tasks. By nature, engineering problem solving requires awareness of the impact on the lives of others, extensive knowledge and creativity. Problem solving is not separate from thinking processes. As identified in Sections 2.2 and 2.4, most problem solving literature comes from fields of well-defined problems and solutions. These are not reflective of engineering problems. Thus there is a need to understand problem solving from the perspective of engineers.
Most of the literature suggests that prior experience ensures good problem solving performance. These studies have focused on how experts resolve problems, often in one specific field. There is a gap between the theory of human problem solving and theories of transferability. As identified in Section 2.1, problems by nature are usually novel situations. Therefore, it is imperative that transfer is achieved through the formal training of engineers. There is a need to understand if and why certain factors and strategies are more useful than others in relation to performance and transfer.

The current literature identified in Sections 2.4 to 2.6 has suggested the skills and qualities that good problem solvers should have. Does this mean that to achieve excellent problem solving ability, all skills and qualities must be acquired – and is that even possible? There is a need to identify the key factors that engineering educators can target to ensure that students improve their problem solving skills.

While existing literature informs the way performance is measured by educators, it is still a challenge due to the complexity of factors involved. In Section 2.7, it was identified that the evaluation of courses is often dependent on the interpretation by educators. A standard measure does not exist. Key factors should be identified and these could then inform the development of a standard evaluation system.

Based on what was learned from the literature, the objectives of this study are:

1. To understand the problem solving process better from the perspective of engineers.
2. To identify what factors impact on problem solving performance with transferability into new problems being taken into account.
3. To identify a set of factors that can be developed standards for measuring problem solving performance.

The following research questions are posed in this thesis:

- What do engineers perceive to be aspects of good problem solving?
- What factors are the most vital for problem solving performance and transferability?
Chapter 3: Methodology

3.1 Mixed methods

This study employed mixed methods. It used both qualitative and quantitative data collection and analysis. The three methods were:

- Grounded Theory (qualitative)
- Repertory Grid Data (qualitative)
- Questionnaires (quantitative)

Grounded Theory (Glaser & Strauss, 1967) was used in this research. Grounded Theory is an inductive approach that attempts to generate a theory from the data collected (Babbie, 2008; Corbin & Strauss, 2008; Dey, 1999; Neuman, 2003; Sarantakos, 1998). Dey (1999) suggested that “the researcher has to set aside theoretical ideas to allow a ‘substantive’ theory to emerge” (p. 1). This study did not use the factors established in previous literature (see Sections 2.1 to 2.6) as guides. Instead, this research attempted to re-establish the factors that impact on the problem solving performance of engineers. The use of Grounded Theory was appropriate as it enabled an inquiry into “variables that have yet to be identified” (Sarantakos, 1998, p.58).

Repertory Grid Technique (RGT) data (Fransella, Bell, & Bannister, 1977) were also used. RGT was developed from the personal construct theory in psychology by Kelly (1963). The assumption behind this method of data collection is that “behind each single act of judgement that a person makes (consciously or unconsciously) lies his or her implicit theory about the realms of events within which he or she is making those judgements” (Fransella, et al., 1977, p. 3). Jankowicz (2004) argued that “to understand how an individual sees the world in his or her own terms we need to find out that person’s construct” (p. 11). This made this method suitable for the purpose of this research, as stated in Section 2.8.

In this study, the qualitative methods were used before the quantitative method. Qualitative methods enable researchers to understand complex phenomena from the perspectives of the participants (Leydens, Moskal, & Pavelich, 2004; Sarantakos, 1998). These methods are aligned to the aims and questions that this research posits, as stated in Section 2.8. Both Grounded Theory and RGT are suitable as these
methods allow investigation of the underlying meanings that a participant may have regarding the concept of good problem solving.

The quantitative component of the study used an online survey. While “qualitative data provide a detailed understanding of a problem... quantitative data provide a more general understanding of a problem” (Creswell & Plano Clark, 2011, p.8). The questionnaire was used after the interview and the RGT, as a questionnaire does not allow “probing, prompting and clarification of questions” (Sarantakos, 1998, p.225). A questionnaire also does not allow underlying additional data to be collected. However, a survey allows the researcher to verify some of the previously gathered information. The survey questions and design were developed using the initial findings of the interviews and the RGT. The reliability and replicability of these findings are tested by disseminating the survey to a larger sample of engineers. The use of a questionnaire enables the researcher to survey a larger sample in time efficient manner.

The use of mixed methods allows the researcher to overcome the weakness of each method as “the limitations of one method can be offset by the strengths of the other method” (Creswell & Plano Clark, 2011, p.8). For example, the results from qualitative data cannot be used to make generalisations but with the use of additional quantitative data, the researcher can generalise the findings. Data resulting from the three methods are then compared. Triangulation is a crucial process that facilitates the checking of data against other collected data. This ensures data validity and reliability (Borrego, Douglas, & Amelink, 2009; Creswell & Plano Clark, 2011; Leydens, et al., 2004; Olds, et al., 2005).

![Figure 3.1: Data triangulation](image-url)
The research design was set out in two phases, as illustrated in Figure 3.2. In the first phase of the study, a semi-structured interview was conducted with each participant. During this session, participants were also asked to carry out the RGT. This process took about 45–60 minutes per session. After the completion of Phase 1 of the research, Phase 2 was implemented, using an online survey that did not take more than 10 minutes to complete. Engineers who participated in the first phase of the research were given a $25 book voucher at the end of the interview session. However, the voucher was not used as an incentive to participate in the research. Recruitment was carried out through the use of a Plain Language Statement that described the research, rather than an overt promotion of the vouchers. Further details on how data was collected and analysed are provided in Sections 3.3 to 3.5.

![Figure 3.2: Research design](image)

### 3.2 Sampling and ethical considerations

Non-probability sampling\(^1\) was used in this research as it is suitable for exploratory and qualitative research (Sarantakos, 1998). Non-probability sampling when used in quantitative study is not fully representative of the population, but “can be valuable as they may be representative for a subgroup of the total population” (Selm & Jankowski, 2006, p. 439). In this study, the population is engineers.

\(^1\) Non-probability sampling: Any technique in which samples are not selected in randomness due to research design or limitation of access to participants (Babbie, 2011).
To target the specific group of participants, purposive sampling\(^2\) was also utilised as it allows the researcher to choose subjects relevant to the study (Rea & Parker, 2005; Sarantakos, 1998). As discussed in Chapter 2, the definition of a good problem solver has previously been established by educators and through the observation of experts. Kelly (1963) proposed that different people have different ideas or concepts of their own reality. Hence, to study what is good problem solving in the engineering field, it makes sense to speak to the engineers. A wide range of engineers from different fields and different experiences were recruited to be key informants for this research.

Participants who were targeted for this study needed to fulfil one or more of the following criteria:

- A student who is currently enrolled in an engineering course
- A student who has completed an engineering course and is currently looking for employment in the field
- A professional working in the engineering field
- A member of the academic staff who teaches engineering

Specific details on how each method and the participants’ recruitment were carried out are discussed in the later sections of this chapter.

Due to the methods of data collection, ethical concerns also had to be considered. Personal information was collected from participants who chose to participate in the qualitative phases of the study. This information was collected for administrative purposes only. For the reporting of results, the data were de-identified by assigning categories and numbers to represent the participants (See Chapter 3.3). Individual identities were not published. Any identifying details (e.g., organisation’s name) discussed in the interview were also removed for the purpose of reporting. Each interview was recorded to ensure that all the information would be captured during the session and all the participants were informed in advance of the recording procedure. Interviews and transcription were carried out by the researcher to maintain participants’ anonymity. Although this study involved student participants, the researcher is an independent, non-teaching staff member and thus no power relationship existed.

\(^2\) Purposeful sampling: The participants are selected on the basis of the researcher’s judgement about which group within the population will be the most useful or representative for the research (Babbie, 2011).
Participation was voluntary and participants were not coerced to take part in the study. Participants were also informed that at any time and stage of the research they could withdraw from the study. Prior to each data collection, participants were given a plain English written statement indicating what the research was about, and agreements to participate in the research were documented.

Ethical approval was sought to address the abovementioned issues and was granted prior to initial data collection in 2009. This project received clearance from the Human Resource Ethics Committee (HREC No. BSETAPP32-09).

3.3 Phase 1: Grounded Theory

Grounded Theory data were collected using taped semi-structured interviews conducted between August 2009 and February 2011. Commonly used in social sciences research, the interviewing method has limitations. Critics have argued that interviewing sometimes results in bias as the presence of the interviewer may affect the results (Sarantakos, 1998). In addition to that, interviews are inconvenient, time consuming, costly and, compared with questionnaires, offer less anonymity and are less effective when trying to extract data that may be sensitive (Sarantakos, 1998). However, as this research did not require the discussion of sensitive information, this was a non-issue. The personal bias of the researcher was taken into account during the data analysis process, as later discussed.

On the other hand, interviews have many benefits over other methodologies. Sarantakos (1998) listed that interviews are flexible and are controllable in many aspects, including environment, question, identity of the respondents, time, date and place. Sarantakos (1998) believed that the use of interviews enables the researcher to capture spontaneous answers. Furthermore, interviews can assist the researcher to gain information on the thoughts and perspectives of the participants (Leydens, et al., 2004; Sarantakos, 1998), which is suitable for this study.

In this study, data analysis was carried out using the technique as suggested by Corbin and Strauss (2008) as opposed to the Glaser (1978, 1992) approach. In comparing the two approaches, Walker and Myrick (2006) suggested that Grounded Theory is “more a science with Strauss and more an art with Glaser” (p. 558). The
procedure proposed by Corbin and Strauss (2008) has a stronger emphasis on the coding and verification process. On the other hand, the Glaser (1978, 1992) approach allows for creative interpretation of data by the researcher. Overall, the Corbin and Strauss (2008) approach utilises a more rigorous and methodical approach to data analysis (Heath & Cowley, 2004; Jones & Alony, 2011; Walker & Myrick, 2006).

The initial participants were recruited from a problem solving elective at RMIT University (Systematic and Inventive Problem Solving [OENG1045]) and also from various engineering organisations. These participants helped to recruit other participants via snowball sampling. The interviews were carried out in cycles as in theoretical sampling (Figure 3.3). In theoretical sampling, “the researcher takes one step at a time with data gathering, followed by analysis, followed by more data gathering until a category reaches a point of ‘saturation”’ (Corbin & Strauss, 2008, p. 146). The focus of theoretical sampling is to follow up on emerging leads that surface from the data until no new themes are identified. In Grounded Theory, data collection occurs concurrently with data analysis until data saturation occurs (Dey, 1999; Suddaby, 2006). In this research, after each cycle, the interviews were transcribed and analysed by the researcher. Interview questions were then adjusted to ensure that better data acquisition could be achieved in the next cycle.

![Figure 3.3: Data collection and data analysis process](image)

The first cycle included seven participants, the second cycle six participants and the third cycle nine participants. Data saturation was observed when carrying out the third cycle, resulting in a total of 22 engineers interviewed, ranging from novices to experts. The sample pool consisted of both students and professionals of varied number of years of industry experience, including 15 male and 7 female engineers. It is well recognised that the proportion of women to men in the science and engineering fields is lower (Beede et al., 2011; Mills, 2010; Mills, Mehrtens, Smith, &

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3 Snowball sampling: A method where participants who have been interviewed are asked to suggest additional people for interviewing (Babie, 2011).
Adams, 2008). Therefore, the gender ratio in this research is representative of the gender proportions in the engineering field. Gender differences were not observed in the data analysis pertaining to problem solving. Hence, the issue of gender was not explored in this study.

Table 3.1: Participants' demographics in Phase 1

<table>
<thead>
<tr>
<th>Classification</th>
<th>Industry experience in full-time engineering field</th>
<th>No. of participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novice Class 1 (N1)</td>
<td>0 years (Students and recent graduates with no industry experience in the engineering field.)</td>
<td>6</td>
</tr>
<tr>
<td>Novice Class 2 (N2)</td>
<td>&lt; 5 years</td>
<td>6</td>
</tr>
<tr>
<td>Mid-level (M)</td>
<td>6–10 years</td>
<td>3</td>
</tr>
<tr>
<td>Experts (E)</td>
<td>&gt;10 years</td>
<td>7</td>
</tr>
</tbody>
</table>

Differences were noticed in the responses of the engineers based on their industry experience. Thus, group classification was based on this. It was observed that young engineers in the research fitted in two categories: Novice Class 1 and Novice Class 2. Professionals with more than 10 years industry experience were classified as experts (Chase & Simon, 1973; Prietula & Simon, 1989). Those in between the novice and expert groups were classified as Mid-level Engineers. Refer to Table 3.1 for the participants’ demographic breakdown. In this thesis, each interviewed participant is identified by their classification (eg. N1) and a participant number (eg. 1). For example, N1-1 refers to Participant 1 from Novice Class 1, and E3 refers to Participant 3 from the Expert group.

As previously indicated, the purpose of qualitative research is to understand a phenomenon from the perspective of a particular group of people. Data from qualitative research are rich and in-depth, making it highly time consuming and impractical to analyse responses from a large number of participants (Borrego, et al., 2009; Leydens, et al., 2004; Mason, 2010). Furthermore, good qualitative research stays true to the concept of data saturation to determine sample size (Mason 2010). Therefore, the number of engineers who participated in this phase of the research was sufficient for proper analysis.
Interview questions (Appendix A) were used as guides but the participants were encouraged to talk as freely as possible about the topic. Questions included how they went about solving problems, examples of good problem solvers and how problem solving can be learned or taught. As the interview progressed, additional questions were asked to probe deeper for the underlying meaning of issues that the participants had raised in the interviews. Examples of additional questions were: “Why did you say that?” and “What do you mean by that?” Throughout each interview, the researcher would also paraphrase to check with the participant that her interpretation of what the participant was saying was accurate.

The constant comparative method of analysing Grounded Theory data was followed in this research. As well as carrying out analysis after each cycle, an overall analysis was also carried out when the cycles concluded. The transcripts were initially micro-analysed with the help of NVivo software to identify common themes, using open coding4. The researcher also listened to all the recordings again to get an overall understanding. Axial coding5 was carried out to identify the relationships between the themes derived from the open-coded data. Once emerging themes had been identified, the researcher went through the transcripts to extract relevant quotes (selective coding). Suddaby (2006) suggested that by carrying out analyses in different ways and a number of times, the researcher is able to get a better depth of understanding of the data. These processes were also vital to ensure validity and rigour in the data analyses.

One of the main issues faced when using qualitative methodology is that analyses are subject to personal biases. In Grounded Theory, instead of trying to suppress biases, the analyst is made aware of personal preconceptions by the use of memos, diagrams and a reflective journal (Appendix B). By engaging in self-reflection exercises while analysing data, a researcher is more likely to be aware when he or she is slanting the data (Corbin & Strauss, 2008). A formal verification session with the participants was also carried out when the full analysis was completed. The verification of results with participants is paramount to ensure validity. This also enables the researcher to be more mindful of personal biases and helps to negate personal assumptions in the analyses (Corbin & Strauss, 2008). All these processes

4 Open-coding: The process of “breaking data apart and delineating concepts to stand for blocks of raw data. At the same time, one is qualifying those concepts in terms of their properties and dimensions.” (Corbin & Strauss, 2008, p. 195)

5 Axial coding: The process of “crosscutting or relating concepts to each other.” (Corbin & Strauss, 2008, p. 195)
are consistent with the practice of ensuring rigour and validity in a qualitative approach (Borrego, et al., 2009; Corbin & Strauss, 2008; Creswell & Miller, 2000; Leydens, et al., 2004; Shenton, 2004; Tracy, 2010).

For these reasons, it is impossible to rush to conclusions too quickly when working with Grounded Theory. The use of this methodology requires a long time for thorough analysis. However, the use of Grounded Theory certainly allows a researcher to capture in-depth and rich data. The Grounded Theory data collection and analysis process is summarised in Figure 3.4.

![Figure 3.4: Summary of the process used with the grounded theory data collection and analysis](image)

**3.4 Phase 1: Repertory Grid Technique**

Phase 1 of the study also utilised Repertory Grid Technique (RGT). The participants who carried out the RGT process were the participants who were interviewed. The RGT process was carried out either straight before or right after the interview, depending on the time availability of each participant. In some cases, the participants chose to do the RGT on another day. As the RGT is a separate component from the interview process, it is believed that the decision of when the RGT is conducted in relation to the interview does not impact the data outcome. Of the 22 participants interviewed, one chose not to do the RGT. Jankowicz (2004) suggested that when RGT fails to collect meaningful data, it is best to drop it.
RGT elicitation can be carried out in a number of ways, depending on the purpose of the project (Fransella, et al., 1977; Jankowicz, 2004). For the purpose of this research, the following RGT process was carried out: Stage 1 – element elicitation, Stage 2 – construct elicitation, followed by rating of constructs, and Stage 3 – binary ratings.

![Figure 3.5: Data elicitation in the RGT process](image)

During the first three interviews, the conventional pen-and-paper method of elicitation was used. However, given the novelty of the method, the participants found it difficult to understand the instructions and in some cases to work within the confines of the instructions. In the later interviews, RGT was carried out using the software Idiogrid. The software helped to clarify instructions and also to form a structure that the participants were able to follow.

In Stage 1 of the RGT (element elicitation), a set of guiding questions was used to elicit the elements. These questions were not limited to the professional realm as the factor of transferability is considered. It is expected that engineers should be able to resolve technical problems as well as non-technical ones beyond the workplace. To elicit the sets of characteristics of good problem solvers, the following questions were asked:

- Someone who you think is a great mentor or teacher to you
- Someone who you think is a good problem solver
- Someone who you would NOT ask for advice or help
- Someone who you think is a good thinker
- Someone who you think is a bad thinker
- A person whom you dislike
- A person whom you do not trust
- Someone whom you would go to for advice or help
- Someone who you think is a bad problem solver
In Stage 2 of the RGT (construct elicitation), triadic comparisons were used. In triadic comparisons, two elements are taken and compared against one element. The question “How are two alike in some way, but different from the third?” (Fransella, et al., 1977) was used. The aim of using opposing constructs is to generate both the negative and the positive characteristics of problem solvers (Figure 3.6). The basis of RGT suggests that “reality and what we make of it is built up of contrasts rather than absolutes” (Jankowicz, 2004, p. 11). The theory behind this method proposes that to investigate the concepts of good problem solving, there is a need to explore the concepts of bad problem solving. The additional elements of “yourself” and “your ideal self” were added in Stage 2 of the RGT process as part of the triadic comparison.

![Figure 3.6: Ideal triadic comparisons](image)

After conducting a number of sessions with the participants, it was observed that the following questions caused issues with the automatic algorithm of Idiogrid in generating triadic comparisons:

- Someone who you think is a great mentor or teacher to you*
- A person whom you dislike*
- A person whom you do not trust*

Ideally, negative elements should be compared with positive elements and vice versa to ensure proper triadic comparisons, as seen in Figure 3.6. However, when these three questions were included, some of the automatic triadic comparison generated by Idiogrid resulted in either positive and positive or negative and negative comparisons, as seen in Figure 3.7. The three questions disrupted the triadic comparison in generating a set of polar traits relating to problem solvers. When such cases occurred, the researcher had to clarify the data and fix it manually during the verification process with the participants. Therefore, the three questions were eventually dropped.
As each characteristic was formed, participants were also asked to rate which of the polar characteristics was more positive for them. This enabled the researcher to classify positive and negative characteristics for problem solvers. In Stage 3 of the RGT process (binary rating), participants were asked to rate the elements “myself” and “my ideal self” against the characteristics identified in Stage 2 of the RGT.

While the RGT enabled the researcher to capture both qualitative (Stage 2) and quantitative (Stage 3) data, this research only considered data collected from Stage 2 of the RGT. It was considered that data generated from this stage of the process was more suited for the research aim and questions, as stated in Section 2.8.

Like the interview, the RGT process is time consuming. As the technique is repetitive, it may lead to “participant fatigue and boredom” (Miles & Rowe, 2004, p. 334). Although most participants were accepting of the process, some participants did not enjoy the process. A number of issues were faced when collecting the RGT data. The unfamiliarity of the method resulted in some participants being quite negative to the process at the beginning. Some participants were concerned about the use of names in the element elicitation phase. To overcome this, participants were reassured that the names generated in Stage 1 of the RGT process would not be used in the analysis.

Due to the repetitive process involved in elicitation, some participants rushed through the process. At times participants included personal characteristics that were not relevant to the research. It became necessary for the researcher to guide the participants through the process, while taking care not to influence their responses. The language barrier was also a factor for participants from non-English-speaking backgrounds, as the RGT is a complex process. However, despite the disadvantages of this method, it is “a fairly effective method of eliciting information” (Miles & Rowe,
In addition, RGT allowed the researcher to understand the respondents’ views in their own terms (Jankowicz, 2004).

The use of Idiogrid allowed immediate analysis, which enabled the verification process to take place as soon as an interview concluded. This process is particularly useful to ensure better accuracy with the data. Participants were shown the results and they were further interviewed if they felt the results and meanings interpreted were not entirely accurate. Then data were adjusted to suit what the participants had additionally commented. Prior to the overall analysis, data clean-up was performed. Despite the initial negative feelings some participants had towards the method, the participants were often pleased to see the results of data analysis.

Common themes were identified and then grouped. The data were then compared with the interview data for cross-verification. Rather than using the existing Grounded Theory data to code the themes in the RGT, specific collective concepts were identified though open coding. This was done as the main purpose of carrying out the RGT is to validate the findings from the Grounded Theory part of the study. The aim is to investigate if similar themes are indentified in the RGT data. The RGT data collection and analysis process is summarised in Figure 3.8.

![Figure 3.8: Summary of the RGT process](image-url)
3.5 Phase 2: Online survey

The last phase of data collection used the survey method. The purposes of this phase were:

1. To enable the researcher to generalise the findings derived from the interview data
2. To confirm or invalidate the observations made from the interview and RGT data

The analyses of the interview and the RGT were compared, and then used to generate the questions and the design of the survey (Figure 3.9). Quotes and ideas generated from the Phase 1 data collection were used. An online survey (Survey Monkey) was used for data collection because of convenience, time and cost (Fowler, 2002; Rea & Parker, 2005).

![Figure 3.9: Development of survey questions](image)

The questionnaire used mainly 5-Likert-scale agree/disagree statements that were generated from the interview and RGT data. In addition, more comprehensive demographic questions were collected. In particular, the survey responders were required to state their industry experience. This was important in order to create a parameter similar to the Phase 1 data collection, to establish the novices and experts within the responders’ pool. Refer to Appendix C for a sample of the survey.

Given that an online survey is self-administered by the participants, a well-designed questionnaire is required (Fowler, 2002; Groves et al., 2004; Rea & Parker, 2005). A stringent approach to questionnaire development was used in this study (Figure 3.10). After an initial survey had been designed, a test of the questionnaire was carried out. This test round consisted of four respondents in both engineering and non-engineering fields. The aim of this process was to ensure that the survey logic and questions used were easily understood, even if the respondent was a non-engineer.
Initial feedback from Round 1 was then used to develop a second version of the questionnaire.

For the second version of the questionnaire, additional questions pertaining to the participant’s problem solving habits were included. A pilot study was then launched and 10 engineers were invited to participate in the next round. Eight of the 10 completed the questionnaire. The responses and feedback from Round 2 were used to develop the final version of the questionnaire. However, the feedback received from the engineers who participated in the pilot round did not require the survey questions to be changed. Thus, the information gathered from the pilot round was able to be included in the full study.

The link to the online survey was sent to the engineers who had participated in the interview and RGT phase of the research. The link was also sent to various engineering organisations and different engineering schools. These participants were then asked to pass along the survey to other engineers they knew (snowball sampling). To increase randomness and representativeness of non-probability sampling, the link was also advertised on the social media sites Facebook, Twitter and LinkedIn. Using this method of disseminating the survey, it was not possible to control the locality of the engineers who participated in the survey (local and international engineers). This was not an issue as country-specific parameters were not relevant to the research. As participation in the survey was anonymous, participant tracking was not required. The use of the online survey ensured the anonymity of the participants (Selm & Jankowski, 2006).

To calculate the response rate, the number of respondents who completed the whole survey was compared with the total number of respondents who started the survey. A total of 273 engineers started the survey. However, the participants stopped completing the survey at different stages of the questionnaire. In the end, only 207 engineers completed the whole survey. Survey incompletion is one of the
disadvantages of using a self-administered questionnaire (Fowler, 2002; Rea & Parker, 2005). However, a 75.8% completed response rate was achieved, which is sufficient to minimise data bias (Malhotra & Grover, 1998; Selm & Jankowski, 2006).

The survey phase was carried out between 29 March 2012 and 16 June 2012. The data were then collected and the statistical software package SPSS was used to analyse the data. At the end of the data collection period, out of the 256 engineers who answered the question pertaining to their profession status, 69% are students, 24% are practising engineers and 7% are academics (Figure 3.11).

![Demographics of engineers](image)

**Figure 3.11:** Demographics of the engineers who responded the question pertaining to their profession status

As presented in Figure 3.12 and Figure 3.13, those who participated in the survey phase of the study included engineers from a variety of fields and age groups.
Figure 3.12: Demographics of the engineers who responded to the question pertaining to the field that they are currently in

Figure 3.13: Demographics of the engineers who responded to the question pertaining to their age
When broken down by gender, about one-third of the engineers who participated in the survey were women (Figure 3.14). Similar to the initial phase of the study (Section 3.3), the gender ratio is representative of the ratio of women in the engineering field.

![Gender Distribution](image)

**Figure 3.14: Demographics of the engineers who responded the question pertaining to their gender**

To make the data consistent and comparable to the interview and RGT data, data clean-up was carried out. The participants were categorised into new groups based on number of years of industry experience similar to those described in Section 3.3. As seen in Figure 3.15, there was a good representation of varied levels of professional engineers despite the majority of those who responded to the survey being engineers with no work experience (i.e., students). Having more novices in research of this kind is common, as exemplified in similar research by Adams (2010).
3.6 Establishing rigour and validity

The previous sections in this chapter covered the processes undertaken to ensure rigour and validity in this study. However, it is important to note that qualitative research utilises different criteria to establish rigour and validity. The term trustworthiness is used in qualitative research instead of rigour and validity (Borrego, et al., 2009; Leydens, et al., 2004; Shenton, 2004). As this research predominantly utilised qualitative methodologies, the strategies suggested by Cresswell and Miller (2000) were used to establish trustworthiness in this study. Creswell and Miller (2000) suggested nine criteria to establish trustworthiness in qualitative research. For specific details of these criteria, refer to Appendix D. They suggested that the purpose and the research design determine which of the nine criteria are the most suitable to be used (Creswell & Miller, 2000). Leydens et al. (2004) suggested that
more than two of the criteria proposed by Creswell and Miller are required to ensure the trustworthiness of qualitative research. This study used seven of the nine criteria to determine trustworthiness. A summary of the strategies is provided in Table 3.2.

Table 3.2: Summary of trustworthiness criteria used in this study

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Action implemented in this study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triangulation</td>
<td>Data from Grounded Theory interviews, RGT and questionnaires were compared and contrasted with one another.</td>
</tr>
<tr>
<td>Disconfirming evidence</td>
<td>When analyses were done, evidence was sought in the transcript – selective coding, as suggested by Corbin and Strauss (2008). Memos, diagrams and a personal journal were also used. For more details, refer to Appendix B.</td>
</tr>
<tr>
<td>Researcher reflexivity</td>
<td>The use of memos, diagrams and a journal during analysis. The question whether the researcher is observing the phenomenon objectively or if bias is slanting the finding is constantly asked in the memos, diagrams and personal journal. For more details, refer to Appendix B.</td>
</tr>
<tr>
<td>Member checking</td>
<td>During the interviews, the researcher constantly paraphrases the participants’ responses to ensure that her understanding is similar to that of the participants’. Participants from Phase 1 of the research were contacted at various points of data analysis to confirm the researcher’s interpretation. A number of the participants had validation meetings with the researcher. Results from the RGT were verified straight after a session was conducted. Participants were also sent copies of any publications arising from the data analysis. Participants who were involved in Phase 1 of the study were contacted again to answer the survey in Phase 2.</td>
</tr>
<tr>
<td>Prolonged engagement in the field</td>
<td>Phase 1 was carried out from August 2009 until early February 2011. More analysis was carried out until early 2012. Conclusion to final findings was not rushed. Data from the interviews and RGT process were coded and re-coded a number of times and in different ways to ensure accuracy, as reported in Sections 3.3 and 3.4.</td>
</tr>
<tr>
<td>Audit trail</td>
<td>Memos, diagrams and a journal were kept to show the evolution of analysis and findings. Discussions with experts in the methodologies were also carried out in order to check that rigorous processes for data collection and analysis were followed.</td>
</tr>
<tr>
<td>Peer debriefing</td>
<td>Peer debriefing was carried out through discussion with other researchers who were not involved with the main research. Findings were also published in double-blind peer-reviewed publications.</td>
</tr>
</tbody>
</table>
Chapter 4: Findings

4.1 Introduction

The data from the research yielded many themes that the engineers believed to be related to concepts of problem solving (Figure 4.1). These themes identified the factors that impact on problem solving performance. While all three methods of gathering data and analysis helped to identify the factors involved in problem solving, the qualitative aspects of the study provided insights into the complexity and the relationships that exist between these factors. Some factors were found to be the key indicators of the transferability of problem solving skills. The next few sections discuss each theme, the links and why these are factors that matter for good problem solving and transferability.

![Figure 4.1: Summary of themes identified in the study](image)

4.2 Understanding the problem: the key to good problem solving

4.2.1 Results

The strongest theme that emerged from the interview data was the concept of understanding the problem. Engineers who participated in Phase 1 of the study indicated that understanding the problem in the first place is crucial for engineering
problem solving (Figure 4.2). They considered this aspect to be the key to whether or not a problem gets resolved well.

The importance of understanding the problem was also observed in the RGT data (Table 4.1). This theme is linked with the processes of researching and taking time to solve problems. It includes both having a wide view and also being able to consider the details. This is the idea of a “balanced” view.

Table 4.1: Understanding the problem theme in RGT data set

<table>
<thead>
<tr>
<th>Theme</th>
<th>Sub-group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understanding the problem</td>
<td>Research / try to understand problem first / problem identification</td>
</tr>
<tr>
<td></td>
<td>Big picture view</td>
</tr>
<tr>
<td></td>
<td>Not jumping to conclusion</td>
</tr>
<tr>
<td></td>
<td>Knowing what is important in a problem</td>
</tr>
<tr>
<td></td>
<td>Balanced view (ability to have a holistic view but also looking at what is important)</td>
</tr>
</tbody>
</table>
Responses from participants indicated that given the complexities that exist in an engineering problem, understanding the problem is a priority. The participants believed that problems in the engineering field require consideration of other areas, for example, the environment. In general, they agreed that good problem solvers are able to consider problems in all their aspects (Figure 4.3).

Figure 4.3: Holistic problem solving theme and examples of quotes from participants

This concept is further strengthened by a comment by one of the participant stressing that problem solving requires a full consideration of the limitations that exists in the problem:

- Taking into considerations the limitations of what you can and can’t do. Take into consideration timeframe, taking consideration how many people you’ve got to do that and what happens if you break one of rules. (M3)

By understanding a problem properly, an engineer is more likely to be able to solve the problem holistically. It is no surprise that in the opinion of some of the participants, good problem solving requires good research. One particular participant said:
[It] is about how much information that you have collected. The more information the better… once you have got all the information and it’s good to have some sort of tool, or assessment tool where you can input all the information together. (N2-4)

This comment also indicates the need for methodology for good problem solving. One of the novice engineers who had taken a problem solving course mentioned how methodology helps with the process of understanding the problem:

How to approach a problem and how to solve it in a systematic manner. So instead of directly going from one side, we are standing outside and looking at the problem all around. Then we are approaching it step by step, looking at the problem from all these sides. (N1-1)

Building a network or charts of problems and how to solve them is actually much clearer you might actually see other problems as well. Sometimes if I were to make a big decision I can just talk to you through it and the solutions are these but if you don’t keep a note or a hard copy, you are just imagining it and you might forget. You might not see other forthcoming problems. But if you actually write it down and make a chart and make it organised you’ll be able to see other things as well. (N1-3)

The need for a systematic tool or method as a factor of good problem solving was also shown in the RGT data (Table 4.2). The participants believed that good problem solvers are analytical people who work in an organised, methodical and systematic manner when resolving a problem. They may also use specific heuristics to break down the problem into manageable chunks.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Sub-group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systematic tool/method</td>
<td>Analytical</td>
</tr>
<tr>
<td></td>
<td>Organised, methodical, systematic person</td>
</tr>
<tr>
<td></td>
<td>Uses specific problem solving heuristics</td>
</tr>
</tbody>
</table>

It was established from the interview and RGT data that problem identification is the key element in establishing good problem solving. The survey was used to
investigate whether this opinion was shared by other engineers and in a larger sample size.

Table 4.3: Understanding the problem in survey data set

<table>
<thead>
<tr>
<th>The key difference between a good problem solver and an average one lies in his/her ability to understand the problem.</th>
<th>Frequency</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
<td>2</td>
<td>0.9</td>
</tr>
<tr>
<td>Disagree</td>
<td>11</td>
<td>5.1</td>
</tr>
<tr>
<td>Neither disagree nor agree</td>
<td>16</td>
<td>7.4</td>
</tr>
<tr>
<td>Agree</td>
<td>105</td>
<td>48.8</td>
</tr>
<tr>
<td>Strongly agree</td>
<td>81</td>
<td>37.7</td>
</tr>
</tbody>
</table>

Over 85% of the engineers who participated in the survey agreed or strongly agreed that the key difference between a good problem solver and an average one is the ability to understand the problem (Table 4.3).

4.2.2 Discussion

The participants believed that good engineering problem solving requires the ability to solve problems holistically – treating any engineering problem as an integral part of a bigger system. Engineering problems seldom exist in isolation. Hence, according to the participants in the study, good performance in engineering problem solving is the ability to resolve problems holistically.

Current problem solving theories and literature suggest that problem solving requires a number of specific skills and steps. Typically, good problem solvers are expected to be able to identify a problem, plan and execute a solution, and then evaluate the solution (Belski, 2002; Carlson & Bloom, 2005; Engineers Australia, 2009; Polya, 1945). The expectation is that good problem solvers must be able to carry out all four specific steps efficiently (Engineers Australia, 2009; Hambur, et al., 2002).
The data in this research show that the key to good problem solving lies in the ability to understand the problem. This finding was reflected in all three data sets collected. The results in this study are supported by the research of Sobek II and Jain (2004), where strong relationships were found between client satisfaction, which they used as a measure of a “good” problem solving outcome, and activities related to problem definition. Litzinger et al. (2010) also suggested that problem solving errors are usually a result of poorly analysed problems. The research of Chi and Glaser (1985) also supported the finding that understanding the problem is very important, especially in complex problems.

This finding also corresponds with the concept of problem space in the theory of human problem solving as suggested by Newell and Simon (1972). They suggested that “when a problem is first presented, it must be recognised and understood” (p. 809). They also believed that during the establishment of the problem space, problem solving occurs and possible solutions are obtained (Newell & Simon, 1972). The statement suggests that problem solving occurs through an understanding of the problem. Furthermore, an understanding of the problem and a generation of a solution occur simultaneously. One of the senior engineers (E3) interviewed during the validation process also agreed and discussed this concept (see Section 4.4.2).

In their research, Adams et al. (2009) found that many academics think that students focus too much on understanding questions rather than identifying and developing methods. While tools and methods for resolving problems were also identified in this study as being important, understanding problems is pivotal for good problem solving. The capacity of a problem solver to establish sound solutions is determined by his or her ability to identify the problem correctly.

Methodologies and tools were discussed by the participants in the research from the perspective of how they help problem analysis. This can be linked to the concept of decomposition (Simon, 1969). A complex problem needs to be broken down into manageable parts in order to resolve it. Often, the research participants suggested that the tools they value are those that assist them to break a problem down into specific parts. This process enables them to view the various interacting parts of the problem, assisting them to view the problem as a whole. Belski and Belski (2008) also observed from their participants’ responses that specific tools within TRIZ were found to be useful as they assisted with problem analysis. It has been found that even simple strategies such as self-explanation can assist with problem analysis.
(Litzinger et al., 2010). It can be proposed then that learning methodologies that assist with problem analysis will enable the problem solver to resolve problems better. It is vital for young engineers to learn methodologies for effective problem representation.

It has been identified that most of the existing literature recognises the importance of understanding the problem. However, the importance has become diluted as some research has proposed several findings without establishing that understanding the problem is the key central factor. This study takes the position that this theme is the core factor for problem solving performance, especially when dealing with complex problems. This aspect is established as the central premise that is the precedence for all the other findings in this study. Findings discussed in this section are translated into a model as seen in Figure 4.4.

4.3 Quickness in problem solving, expertise and impact of assumptions

4.3.1 Results

Another recurring concept raised by the participants during the interviews was the idea of quickness in good problem solving:

I knew thinking about a problem and solving it **quickly** and as soon as possible with the right way is the most appropriate. (N1-3)
Some people have the capability to think fast. They have a problem and then they can just come up with the solution straight away that’s what I call people with good thinking skills. (N1-6)

Some of the experts also commented:

Some individuals are quick and bright and imagine a problem solution, or a range of problem solutions quickly. (E3)

There are some basics skills required to be able to solve problems quickly and fast. (E4)

I guess one measure [of problem solving skills] is the ability to solve problems that other people can’t. Or they can do it faster or better. (E6)

These comments seem to suggest that the ability to solve problems quickly is perceived as indicative of good problem solving.

The idea of being able to come up with ideas quickly as a desirable factor of good problem solving was also observed in the RGT data. However, it was only raised once by a novice participant. One of the participants who has five years industry experience first linked the idea of being able to solve problems quickly to the ability to solve problems well:

He can solve problems, he does have good problem solving skills… he’s a fast thinker… he gets the job done. That’s the main thing. (N2-2)

Interestingly, he later backtracked and admitted:

He is selfish he tries to do shortcuts. At the end of the day, the job is done but it’s not done properly. So there are flaws everywhere. And even though it’s done, you have to re-do the test because it’s not valid…. Problem solving… look he’s probably a quick-thinker but in terms of solving the problem completely he’s not. He’s a quick-thinker. Hmm…maybe I’m wrong (laugh)… You have to be a quick thinker and you have to be able to solve the problem completely too. (N2-2)
In further investigating the idea of the connection between quickness and good problem solving, it became clearer that although quick-thinking is valued, it is not indicative of good problem solving. The concept of “quick” in problem solving also has different meanings in the perceptions of the different groups of participants. It was observed that novice engineers tend to associate the idea of quickness with the concept of getting the job done. Quickness is linked by young engineers to solving the problem (i.e., the end). Comments from some of the experts, on the other hand, recognise that the “quick” solution addresses the time constraint that exists and is expected in the industry. However, it is not the end of the problem solving process:

Provide quick answers but put provisos in them if it was a limited sample set that you only had a chance to look at. You also have to be reasonably quick in providing answers if they are needed quickly or you can take your time and be thorough if the time is available there. But I think the ability to not jump into the first answer that comes into your mind, but to properly think around it and test it. (E3)

In addition, the same participant stressed the need to evaluate a quick solution to ensure that it addresses the problem:

Competition is getting more intense, we need solutions quicker... some developers create things very quickly so that we can take ideas of what can be done into a product, an application and try it out. It has to be done quickly, obviously to get to market But that's not the all and end all. Because sometimes you do something and you say ah, that's not quite right. It needs to go somewhere else. Needs to be improved, to go into a different direction of development and so you may need to change direction one or two or three times before you find something that is genuinely useful. (E3)

Therefore, novice engineers perceive “quickness” as a focus on solution generation and getting the job done. On the other hand, expert engineers believe that being able to diagnose problems and coming up with solutions quickly can address a problem immediately, but to make sure that the problem is resolved well, continuous evaluation is required. This is summarised in Table 4.4.
Table 4.4: Summary of different opinions between the novice and the expert on quickness

<table>
<thead>
<tr>
<th>Novice</th>
<th>Theme</th>
<th>Expert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus on: Solution generation Getting the job done</td>
<td>Quickness</td>
<td>Focus on: Understanding the problem Continuous evaluation required to make sure solution fits the problem.</td>
</tr>
</tbody>
</table>

The question is why the young engineers link good problem solving and quickness. Comments from the younger engineers may explain this link:

[Good problem solvers] are really wise… I found them to be quick thinkers. Their mind is just switched on and they can always come up with suggestions, ideas…. their mind seemed to be switch fast…. Sometimes when you ask them questions they can just mentally work out a solution. I guess they have really strong conceptual mind. They can picture the problem inside their head and just solve it in their mind. (N2-4)

He could see the details, and he could see the big picture straight away to come up with the idea …. He already sort of knew that the concept could fit into the vehicle. (M2)

The comments above indicate that in the opinions of the young engineers good problem solvers do indeed come up with solutions quicker than others. The second participant quoted above (M2) also suggested that it is because the good problem solvers can somehow recognise the sort of problem being faced based on past experience. The comments suggested that prior experience has a role and results in the ability to recognise the problem being faced at a much faster rate. Hence, based on the data, it is proposed that experts are more likely to be quick in problem identification, resulting in a quick transition to solution. This idea is also supported by the survey data (Table 4.5).

Overall, it was observed from the data that most of the engineers surveyed spent the most time in the planning stage (35.85%). However, when the data were broken down according to the groups based on industry experience, an interesting pattern emerged. Engineers with no industry experience (N1) spent the least time of the four
groups on understanding the problem compared to the time spent on the other stages of problem solving (27.79% on stage 1, 37.92% on stage 2 and 34.29% on stage 3).

Table 4.5: Time allocated by engineers in the survey to different stages of the problem solving process

Think back of ONE engineering problem that you had resolved recently. Please allocate how much time you spent on each problem solving stage stated below (in percentages out of a total 100, e.g., 30, 50, 20).

<table>
<thead>
<tr>
<th>No. of years of industry experience</th>
<th>No. of engineers who responded to the question</th>
<th>Understanding the problem (diagnosing the problem)</th>
<th>Planning the solution/s (identifying the possible solution/s, and planning the implementation)</th>
<th>Implementation of the solution/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>no industry experience (N1)</td>
<td>85</td>
<td>M=27.79 SD=13.895</td>
<td>M=37.92 SD=16.935</td>
<td>M=34.29 SD=19.853</td>
</tr>
<tr>
<td>less than 5 years industry experience (N2)</td>
<td>63</td>
<td>M=33.17 SD=13.950</td>
<td>M=35.87 SD=15.307</td>
<td>M=31.27 SD=15.912</td>
</tr>
<tr>
<td>6–10 years industry experience (M)</td>
<td>22</td>
<td>M=44.55 SD=16.029</td>
<td>M=30.68 SD=11.474</td>
<td>M=24.77 SD=14.013</td>
</tr>
<tr>
<td>more than 10 years industry experience (E)</td>
<td>27</td>
<td>M=31.48 SD=17.586</td>
<td>M=33.52 SD=12.921</td>
<td>M=35.00 SD=18.605</td>
</tr>
<tr>
<td>Total</td>
<td>197</td>
<td>M=31.89 SD=15.449</td>
<td>M=35.85 SD=15.456</td>
<td>M=32.36 SD=18.039</td>
</tr>
</tbody>
</table>

*18 outliers removed prior to analysis (outliers=responses that did not add up to 100%)

The trend changed as the engineers surveyed gained industry experience and it was observed that more time was spent on understanding the problem than on implementation. Although most of the time was still spent on the planning stage (35.87%), those with less than five years industry experience (N2) reported spending more time on understanding the problem (33.17%) than on implementation (31.27%). As the engineers gained 6 to 10 years industry experience (M), a clear reversal was observed. Most of the time was spent on understanding the problem (44.55%), with
30.68% spent on planning and 24.77% spent on implementation, indicating that in this group there is a focus on problem identification. The engineers with industry experience of more than 10 years (E) reported spending less time on the problem identification stage (31.48%) than on the other stages (33.52% on stage 2 and 35% on stage 3). The trend is similar to that in the N1 group, engineers with no industry experience.

The spread of the responses as to how much time was spent on the different stages of problem solving are presented in Figure 4.5, 4.6 and 4.7.

Figure 4.5: The spread of responses on how much time is spent on understanding the problem according to the different groups of engineers

In comparing the spread of responses between the groups on how much time is spent in understanding the problem (Figure 4.5), those in the N1, N2 and E group had a similar trend of spread, with medians at the same point (Median=30).
When investigating how much time is spent in the planning stage (Figure 4.6), interestingly those in the N1 group has the largest spread. The spread of responses becomes narrower as more experience is gained. This indicates that the more experience an engineer gained in the industry, the more likely they are to be aware on how much time is required to spend on planning when resolving problems.

When it comes to how much time is spent on implementation (Figure 4.7), those in the N1 and N2 groups has a wider spread of responses compared to those in the M and E groups. This again indicates that awareness on how much time is spent on implementation improves with industry experience.
Before investigating whether statistical significance existed in the responses of these groups, the Kolmogorov-Smirnov Test was carried out to determine the most suitable statistical test for the data obtained. Due to the violation of parametric assumption of normal distribution in the data, the non-parametric test, the Kruskal-Wallis Test, was used. Statistical significance was found between the groups in their responses to how much time was spent understanding the problem (p=0.000).

To determine where the statistical significance occurred in the data, each individual group was tested in pairs using the Mann-Whitney U-Test (Table 4.6). Statistical significance was found in all groups except for when those in the N1 and N2 groups were compared to the Expert group (p>0.01).
Table 4.6: Statistical analysis on group comparisons of time spent on understanding the problem

<table>
<thead>
<tr>
<th>Comparison group</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1 – N2</td>
<td>0.020*</td>
</tr>
<tr>
<td>N1 – M</td>
<td>0.000*</td>
</tr>
<tr>
<td>N1 - E</td>
<td>0.445</td>
</tr>
<tr>
<td>N2 – M</td>
<td>0.005*</td>
</tr>
<tr>
<td>N2 - E</td>
<td>0.378</td>
</tr>
<tr>
<td>M - E</td>
<td>0.005*</td>
</tr>
</tbody>
</table>

*Statistical significance is observed (p<0.05 or p<0.01).

Experience was certainly valued by our participants in Phase 1 of the study. Participants generally suggested that people are good problem solvers because of their experience. One young engineer in our research indicated:

I can say that good thinkers are the people who already faced the problem before. So they have more experience in the problem, facing problems. (N1-4)

The above statement indicates that experience would be a benefit when facing problems similar to those encountered before. This was reiterated by one of the senior engineers interviewed, who commented:

Experience teaches you to recognise what to expect. (E3)

On the other hand, this comment also highlighted that experience may result in creating biases when confronting a new problem. The participants also stressed that the problem solver’s perceptions and assumptions influence his or her interpretation of the problem (Figure 4.8). One participant’s comment gave an example of how misanalyses and assumptions can impact on a project outcome:

Only a couple of weeks ago actually we got a problem with one of the projects. So basically we almost finished the project but what we found… when we were about to test it whether it was working or not, we found another problem… We managed to find another problem because we tried to fix one thing. The second
The problem actually was **not analysed properly** because it was out of the scope of the project. When we tried to do the project, we **assumed** that one of the testing procedures is actually working. But when we tested it we found out that it was actually not working. That’s why we couldn’t test all of the project. (N2-1)

![Figure 4.8: The effect of assumptions in problem analysis theme and examples of quotes from participants](image)

These comments indicate that past experience and expertise may impact negatively on problem analysis. Past experience shapes the problem solver’s perception of a new problem. This was also evident from the comments of some of the engineers interviewed:

> You can have someone with lots of experiences and they might have a lot of knowledge on something but once it comes down to something new they might not be able to just to tackle it at all because they’ve got their head set in the same spot. (N1-1)

> That’s a big trap to get into. Just because something worked once this way, it always works. (M1)

Participants in the survey were asked if they believed expert engineers were able to consider new problems with new perspectives (Table 4.7). Although overall they
agreed with this statement, less than 50% of those surveyed agreed or strongly agreed that expert engineers are more likely to consider new problems from a new perspective.

Table 4.7: Survey response on expertise and novel problems

<table>
<thead>
<tr>
<th>Expert engineers are better at considering a novel problem with new perspectives compared to novice engineers.</th>
<th>Frequency</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
<td>8</td>
<td>3.8</td>
</tr>
<tr>
<td>Disagree</td>
<td>59</td>
<td>28.1</td>
</tr>
<tr>
<td>Neither disagree or agree</td>
<td>55</td>
<td>26.2</td>
</tr>
<tr>
<td>Agree</td>
<td>68</td>
<td>32.4</td>
</tr>
<tr>
<td>Strongly agree</td>
<td>20</td>
<td>9.5</td>
</tr>
</tbody>
</table>

The survey responses were broken down into the different groups based on industry experience (Table 4.8). It was observed that the majority of those in the expert group (E) who responded to the question actually disagreed or strongly disagreed with the statement (46.4%). The majority of those with no industry experience (N1) tended to agree with the statement (50.5%), while the majority of those with less than five years industry experience (N2) tended to disagree or strongly disagree with the statement (46.4%). Those with 6 to 10 years industry experience (M) had 32% agreeing and 24% disagreeing. No statistical significance was observed in the responses of the different groups of engineers (p>0.05).
Table 4.8: Survey responses on expertise and novel problems broken down into groups according to industry experience

<table>
<thead>
<tr>
<th>Expert engineers are better at considering a novel problem with new perspectives compared to novice engineers.</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neither disagree nor agree</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>no industry experience (N1)</td>
<td>4</td>
<td>16</td>
<td>22</td>
<td>32</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>4.7%</td>
<td>18.8%</td>
<td>25.9%</td>
<td>37.6%</td>
<td>12.9%</td>
</tr>
<tr>
<td>less than 5 years industry experience (N2)</td>
<td>2</td>
<td>26</td>
<td>19</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>2.8%</td>
<td>36.1%</td>
<td>26.4%</td>
<td>27.8%</td>
<td>6.9%</td>
</tr>
<tr>
<td>6-10 years industry experience (M)</td>
<td>0</td>
<td>6</td>
<td>11</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>0.0%</td>
<td>24.0%</td>
<td>44.0%</td>
<td>24.0%</td>
<td>8.0%</td>
</tr>
<tr>
<td>more than 10 years industry experience (E)</td>
<td>2</td>
<td>11</td>
<td>3</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>7.1%</td>
<td>39.3%</td>
<td>10.7%</td>
<td>35.7%</td>
<td>7.1%</td>
</tr>
</tbody>
</table>

The idea that experience and expertise are valued was also observed in the RGT results (Table 4.9). At the same time, the concept of the value of less experience was also found.

Table 4.9: Dual concepts of the value of prior experience and expertise in the RGT result

<table>
<thead>
<tr>
<th>Theme</th>
<th>Sub-group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experience/expertise</td>
<td>Older in age</td>
</tr>
<tr>
<td></td>
<td>More experience</td>
</tr>
<tr>
<td>Less experienced</td>
<td>Younger aged</td>
</tr>
<tr>
<td></td>
<td>More opportunity to learn</td>
</tr>
</tbody>
</table>
4.3.2 Discussion

The idea that “quick” is linked to good problem solving was raised by some participants. This theme is interesting as it seems to contradict what the participants considered to be an important aspect of good problem solving: taking time to really understand the problem, as established in Section 4.2. However, in further analysis of the interview data, it became clear that participants in Phase 1 of the study identified as novices (N1 and N2) and experts (E) perceived this concept differently.

Based on the findings of this study, it is proposed that young engineers tend to believe that solving a problem quickly is indicative of good problem solving ability and is solution focused. In contrast, expert engineers recognise that “quick” problem solving only addresses the time constraints that exist in the workplace. Expert engineers are likely to recognise that an initial solution may not be holistic, and therefore the problem solving process continues. The data indicate that further verification is required when proposing “quick” solutions.

The data suggest that there is a misconception that the ability to solve problems quickly is linked to good problem solving performance. Further analysis of the interview data suggests that this misconception arises from observations of younger engineers on how the experts in their lives resolve problems. As shown in the interview data, sometimes experts tend to work out problems mentally (non-verbally). However, the solution is often all that is manifested. While different aspects are actually at play, novices interpret this behaviour as quickly coming up with a solution. Hence, the younger engineers in the research assume that thinking quickly for solution generation is a characteristic that needs to be developed.

This concept is supported by the findings of current literature that experts are considered to be better problem solvers due to the schemata they have in their long-term memory (Belski & Belski, 2008; Chi, et al., 1982; Gick, 1986; Newell & Simon, 1972). As identified by Newell and Simon (1972), problem solving requires pattern recognition and the use of long-term and short-term memories. Recent literature in cognitive science has identified that experts are able to by-pass the search strategy when resolving problems due to their well-developed schemata which enable them to solve problems better and at a much quicker rate (Kalyuga, Ayres, Chandler, & Sweller, 2003; Kalyuga, et al., 2010).
This suggestion is supported by the survey data presented in Table 4.5 and Figure 4.5. The statistical information provided in Table 4.5, Figure 4.5-4.7 may also support the previous finding discussed in Section 4.2 that understanding the problem is the most crucial aspect of problem solving. Of all the stages prescribed by literature as indicative of a general good problem solving procedure, the only statistical significance was observed at the stage of understanding the problem. The data suggest that as industry experience is gained, the only factor that changes among all the problem solving stages is the understanding of the problem. This suggests that as engineers gain more expertise, the time spent on problem understanding increases, at least until they reach the expert level.

The results of the survey show that, as expertise is achieved, the amount of time spent in understanding the problem decreases compared to those in the N2 and M groups. The data suggest that experience and expertise impact on the problem diagnosis stage. The data support the idea that expertise allows a problem solver to recognise problems faster. As observed in the statistical significance test (Table 4.6), those in the N1 and E groups were similar. Both these groups spent the least amount of time in understanding the problem phase. As established in Section 4.2, understanding the problem is the most crucial factor in problem solving performance. Novices with no prior industry experience spend the least amount of time in this problem solving phase in comparisons to all the other groups. This signifies that such misconception may impact on the overall problem solving performance.

The survey data indicate that prior experience gives an edge for problem solvers to be able to understand problems at a much faster rate. However, can it then be assumed that expert engineers are better problem solvers? While the existing literature (Atman, et al., 1999; Bilalic, et al., 2009; Carlson & Bloom, 2005; Chi, et al., 1982; Gick, 1986; Gobet & Simon, 1996; Newell & Simon, 1972; Simon, 1969) tends to assume that this is the case, the data in this study indicate that this is not so. The three sets of data suggest that experience and expertise are valued and give an advantage when dealing with similar problems. From the interview and survey data results, it can then be proposed that experience and expertise have greater impacts on direct transfer.

It is important to recognise that when it comes to indirect transfer, prior experience and expertise may have a negating effect. It was discovered that a problem solver’s
interpretation of the world significantly influences his or her understanding of the problem. This finding is supported by the work of Carlson and Bloom (2005), who observed that expert decisions were affected by beliefs about mathematical concepts. In reiterating the link between problem solving and thinking, de Bono (1996) emphasised that thinking has everything to do with perception. He argued that “perception is the most important part of thinking” (de Bono, 1996, p. 15). Wilson (2000) and van Gelder (2005) also supported the idea that perception affects thinking skills. Perkins (cited in de Bono, 1996) found that errors in thinking are usually caused by errors in perception.

It can be suggested that when facing completely new problems, experience and expertise may increase bias and assumptions. Participants in the research believed that prior experience and expertise may also result in the inability to approach new problems in new ways. Interestingly, when Phase 2 participants were surveyed (Tables 4.7 and 4.8) regarding the impact of expertise on new problems, overall the results tended to be spread over the agree-disagree spectrum. However, it is interesting to note that more of the expert group (E) than the other groups actually disagreed or strongly disagreed that experts are better at considering novel problems with new perspectives. This supports the suggestion that when it comes to a new problem, prior experience and expertise may impact negatively on the understanding of the problem. This finding is supported by recent studies from the cognitive science perspective which have discussed a possible adverse impact of expertise on problem solving in a new situation (Belski & Belski, 2008; Kalyuga, et al., 2003; Kalyuga, et al., 2010).

Although quick problem solving is rarely mentioned in the current literature, this study has identified that there is a misconception of quickness in problem solving. This misconception has been identified as being the result of novices observing their expert counterparts resolving problems. Existing literature tends to suggest that prior experience and expertise ensure better problem solving performance. These studies may contribute to the exacerbation of the misconception that the quick problem solving by experts is something to be aspired to. However, the results of this study found that expertise may have an adverse impact on problem solving performance, especially when it comes to new problems. Assumptions are found to influence how a problem is perceived. Prior experience and expertise may have a negative effect on the process of understanding a problem as these are observed to increase bias. These findings are summarised in Figure 4.9.
4.4 Evaluation and reflection, “options” and self-efficacy

4.4.1 Results

As seen in Section 4.3, expert engineers understand the need for evaluation and reflection in engineering problem solving. The theme was also observed in the RGT responses (Table 4.10).
It was observed that engineers who have industry experience are more likely to be aware that engineering problem solving requires many reiterations before the problem gets resolved. One novice engineer who has two years working experience mentioned:

You’ll never get a project done 100% anyway in the first try. Something always go wrong. (N2-1)

However, there is a difference in perception between young and expert engineers about evaluation and reflection when solving a problem. This was exemplified when the same engineer (N2-1) also said:

Sometimes I do reflect. Probably not usually, it’s only good when you are stuck on something….I **usually only reflect when I am stuck in something.** (N2-1)

This statement is an example of the perception that the process of evaluation and reflection is only required when something goes wrong. The statement suggests that younger engineers may consider evaluation only if an initial solution does not address the problem. In contrast, the senior engineers in the research believed that evaluation and reflection is part of the process, as seen in Sections 4.3. A senior engineer is aware that to arrive at a solution that would satisfy the problem holistically, one must carry out evaluations.
There were also different opinions on what should be evaluated. Younger engineers tend to evaluate procedure, as exemplified by these statements:

You reflect, and you think about what have you done and you try to find things that you have done that you can relate to the problem now. (N2-1)

[If there is a problem] I would actually go back to step one. Check what you've done…step by step and start troubleshooting. That's what it is. We call it troubleshooting. We start from initial check, once everything is checked then we determined what the problem is. (N2-2)

Senior engineers believed that in order to understand the problem, they also need to evaluate and reflect on their own assumptions:

You have to ask yourself the question what happens if I’m wrong in my assumptions. How will that affect my solutions? When somebody misuses a product will it break straight away? Have I taken that into account? … You've got to test your solution out and evolve it so understanding the problem, understanding the situation, understanding what is required and understanding you may have to keep and open mind and reiterate it. (E3)

I think it’s important that you are able to recognise flaws and understand that they may invalidate what you are thinking and have to be prepared to be able to see them and deal with them…. … you have to be critical of yourself, be critical of the solution that you've found and not assume that it is correct too soon or that you've got the answer too soon. Or that you understand it before you really do. (E6)

As summarised in Table 4.11, the interview data suggest that expert engineers evaluate both procedures and personal assumptions. On the other hand, younger engineers tend to focus on procedures. The data also suggest that young engineers are more likely to carry out evaluation and reflection only when their solution is wrong, while experts seem to suggest that the process of evaluation and reflection needs to be carried out regardless.
Table 4.11: Summary of differences of opinions on the theme of evaluation and reflection between novice and expert engineers in the study

<table>
<thead>
<tr>
<th>Novice</th>
<th>Theme</th>
<th>Expert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus on:</td>
<td>Evaluation and reflection</td>
<td>Focus on:</td>
</tr>
<tr>
<td>Evaluation if initial</td>
<td></td>
<td>Always evaluate.</td>
</tr>
<tr>
<td>solution was wrong.</td>
<td></td>
<td>Evaluate both procedure and personal</td>
</tr>
<tr>
<td>Evaluate steps or</td>
<td></td>
<td>assumptions.</td>
</tr>
<tr>
<td>procedure to see where</td>
<td></td>
<td></td>
</tr>
<tr>
<td>they went wrong.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The difference between the opinions of the two groups can be attributed to the degree of industry experience. As mentioned previously, industry experience makes engineers more aware that problems cannot be resolved in one try. A senior engineer reinforced this when he commented:

[A fresh graduate engineer] doesn’t have the experience so they might have the aptitude, they may not have the knowledge or the experience to know, to better identify the things that are important, and things that aren’t important. (E6)

The comment above suggests that as engineers get more industry experience, the more likely they are to understand the need for evaluation and reflection. In Phase 2 of the research, the engineers were surveyed about evaluation. About 70% of the engineers surveyed reported that they always carry out the evaluation process when resolving a problem (Table 4.12).

Table 4.12: Survey responses on engineers and the evaluation process

<table>
<thead>
<tr>
<th></th>
<th>Frequency</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>when required only</td>
<td>66</td>
<td>29.9</td>
</tr>
<tr>
<td>always</td>
<td>155</td>
<td>70.1</td>
</tr>
</tbody>
</table>

To investigate further if there are differences in the way specific groups respond to this question, the information was sorted according to the engineers’ industry experience (Table 4.13). Of the engineers who had no industry experience at all (N1), 63.4% reported that they always evaluate their solutions. 72% of those with less than five years experience (N2) and 76% of those with 6 to 10 years experience
(M) reported that they always evaluate their solutions. Less than 20% of those with more than 10 years experience (E) reported carrying out evaluation only when required. As the data is categorical\(^6\), the Pearson’s chi-square test is used to analyse for statistical significance between the responses of the different groups. The differences between the groups showed no statistical significance (p>0.05). Nonetheless, the data trend supports the idea that the more industry experience engineers have, the more likely they are to be aware of the need for evaluation and reflection.

Table 4.13: Survey responses of engineers and the evaluation process broken down into groups based on industry experience

<table>
<thead>
<tr>
<th>Evaluation</th>
<th>when required only</th>
<th>always</th>
</tr>
</thead>
<tbody>
<tr>
<td>no industry experience (N1)</td>
<td>34</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>36.6%</td>
<td>63.4%</td>
</tr>
<tr>
<td>less than 5 years industry experience (N2)</td>
<td>21</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>28.0%</td>
<td>72.0%</td>
</tr>
<tr>
<td>6–10 years industry experience (M)</td>
<td>6</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>24.0%</td>
<td>76.0%</td>
</tr>
<tr>
<td>more than 10 years industry experience (E)</td>
<td>5</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>17.9%</td>
<td>82.1%</td>
</tr>
</tbody>
</table>

The interview data also showed that evaluation and reflection is a crucial process that aids the long-term development of problem solving skills. In the survey, the respondents were asked specifically whether or not they believed that formal education ensures good problem solving skills (Table 4.14). The general response was split almost evenly, with 36.2% disagreeing and 34.7% agreeing. Participants in

\(^6\) Categorical data: Variables that are made up of categories of objects/entities (Field, 2009). For example, either a yes or a no response type of question results in a categorical data. In this data set, when it comes to the habit of evaluating when problem solving the response is either ‘when required only’ or ‘always’.

- 67 -
the survey were also asked if good problem solving develops from industry experience (Table 4.15). Only about 50% of the engineers surveyed agreed with the statement.

Table 4.14: Survey responses on the development of problem solving skills through formal education

<table>
<thead>
<tr>
<th>Having formal education results in good problem solving skills.</th>
<th>Frequency</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
<td>14</td>
<td>6.6</td>
</tr>
<tr>
<td>Disagree</td>
<td>63</td>
<td>29.6</td>
</tr>
<tr>
<td>Neither disagree nor agree</td>
<td>62</td>
<td>29.1</td>
</tr>
<tr>
<td>Agree</td>
<td>61</td>
<td>28.6</td>
</tr>
<tr>
<td>Strongly agree</td>
<td>13</td>
<td>6.1</td>
</tr>
</tbody>
</table>

Table 4.15: Survey responses on the development of problem solving skills through industry experience

<table>
<thead>
<tr>
<th>Good problem solving skills are only developed after having practical experience in the industry.</th>
<th>Frequency</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
<td>7</td>
<td>3.3</td>
</tr>
<tr>
<td>Disagree</td>
<td>47</td>
<td>22.1</td>
</tr>
<tr>
<td>Neither disagree nor agree</td>
<td>57</td>
<td>26.8</td>
</tr>
<tr>
<td>Agree</td>
<td>78</td>
<td>36.6</td>
</tr>
<tr>
<td>Strongly agree</td>
<td>24</td>
<td>11.3</td>
</tr>
</tbody>
</table>

Interestingly, the engineers who were interviewed believed that life experiences have contributed better to their problem solving skills than formal education. When the participants were asked about learning problem solving, they indicated that the best learning occurs as one goes through life. Participants considered problem solving learnt from life experiences to be of more value, as seen in the comments below:
It’s something that you develop through life. You can’t learn this in a course. (N2-3)

[Learning problem solving] I think life it does. Life does. I think not just courses, I think it’s life. (E1)

Life experience, attitude. And to a certain extent how you solved problems in everyday life. Even before you learned it in uni. (N2-6)

One engineer explained in the interview the difference between learning problem solving in a university setting and in real life:

In university we learn a bit of decision making. We do a lot of projects at [name of university], small projects, presentations. Which is helpful. But the main thing is when dealing with real life, you can’t make big mistakes. In university if you make a big mistake you can actually come back to your lecturer and say sorry. Or your lecturer can fix it for you. (N2-1)

The statement suggests that in real life situations, the problem solver is forced to consider and deal with consequences. Learning from mistakes is actually valued by the participants. Some of the engineers suggested that when the way they understand things is constantly challenged, they learn better (Figure 4.10).

Figure 4.10: Challenging understanding theme and examples of quotes from participants
Moreover, facing challenges allows them a change of mind-set, which is important when facing new problems:

It’s only when you bumped into a brick wall you’d you I don’t think I can go through this that you go I think I’m going to have to change it [the way I think]…

[good problem solving] is not hitting the road block then being unable to move. Because a problem is a problem because it’s hard. Not because it's an exercise to test your ability. And it’s a problem because nobody has been able to solve it and it needs a solution. And so when you hit the road block, you need to move around that road block in your own mind. (E3)

I guess the people who have the best problem solving skills are the ones that continually put themselves in situations where they have to come up with something different or apply their thought processes in a different way. (M2)

They considered that learning resulting from a change of perception deepens their understanding. Responses from the participants also suggested that the more they are exposed to problems, the more they become aware of the way they approached them, and this awareness helps them to develop their problem solving skills, as seen in the comment below:

If you were told or shown by someone I don’t think it will ever work quite as well…you don’t have the reasoning behind it, while if you thought through a process all the little steps some worked some didn’t but if someone tries to say think about this and think about this you are only going to think about the 5 things he told you. You might miss the sixth thing that he didn’t tell you. Or the 6th thing that came up in a situation that is slightly different to the one he taught you about. Whereas maybe if you had done that process yourself you have the ability to think outside the box a little more and consider it more broadly…[in addition] if you are left alone you have to search those things out for yourself a little bit more. That makes you a stronger engineer because you’ve sought that knowledge yourself rather than being told it. (M2)

The other difference between learning from life and learning in a formal educational setting is “options”, which was identified as anything that makes problem solving easier, such as external help (Figure 4.11). Options can include policies that allow a problem solver to choose not to face challenges. In particular, options can take away the need for understanding, impacting transferability. One student interviewed, despite having learned problem solving formally, said:
I didn’t know anything. I just answered whatever I came up with at first and I didn’t even bother using the Su-field. I just think the answers first then use Su-field…. I’m like the person who relies heavily on others. They know me. I’m like the person who during exam time, most people come to me as they think I know the answers as I’ll get it from someone. (N1-2)

In contrast, another participant stressed the importance of challenges to the development of problem solving skills:

I found that the courses that I got the most out of were the ones where I was forced to do work myself and figure it out myself. I was a bad problem solver until I was forced to do it, to figure it out for myself. (N2-5)

‘... I think for that person it was simply easier to ask somebody else. Than it was to go and find the solution. Which is not really solving the problem, but just passing it on.’ (N2-6)

‘[on difficult courses] if it was too hard I would drop it immediately. I’ve been in that situation before everybody say it’s difficult or it’s easy. But then you never know until you take it. So that’s where you can level where you are up to. Thankfully the school has the rule or the regulation that in the first 3 weeks if you are not happy with your subjects you can just drop it... just no penalty.’ (N1-3)

‘... my time in uni is like get to know your mentor more, especially the lab teachers and get close to them and they’ll explain to you stuff in a different way when they are teaching you in class. They will be friendlier and they’ll answer as you are keen to study and keen to gain information from them... I’ve been using this approach to each lab teacher and getting outstanding results and they like me and they ask me how come you are doing so bad in tests and but great in my class.’ (N1-2)

Figure 4.11: Detrimental effect of “options” theme and examples of quotes from participants
When further questioned about the concepts of learning, the younger engineers who were interviewed believed that the amount of experience they gain contributes to the learning process:

I guess you develop those skills [problem solving] as you have the experience. (M2)

Of course [how we developed it is] from experience. If we face more problems and we come up with lots of solutions, it will help us with that skill. (N1-6)

Senior engineers, on the other hand, highlighted that expertise can result in a negative impact on the learning process. This was exemplified when one of the senior engineers interviewed commented:

[Learning problem solving] I want to qualify only to a point... one thing I noticed is many people including myself, you learn and you learn and then you saturate yourself and you don’t learn beyond that. I don’t think you keep on learning all the time. You do learn things but the slope of the curve becomes slow. (E4)

The expert E4 suggested that when a person is over-saturated with knowledge, learning slows down. One other senior engineer even went further to attribute this to the malleability of personality:

I think probably as you get older your personality tends to solidify more and become more of an extreme personality type. And so if that personality type is a personality that is a problem solver, you’d probably become better at it. Whereas if you are not you probably become worse at it. When you are a fresh graduate you are neither of those two yet, I guess you are more flexible. You are coming from an environment where, more so in the working environment I think you are taking new information all the time and learning continually and intellectually far more stimulated than after 17 years in [company name] or whatever, depending on your job and what you do in your outside life. But I think that helps as well, because it primes you for your learning and thinking and it’s very fresh. (E6)

As mentioned previously, transferable learning requires overcoming challenges. One of the engineers interviewed suggested:

I think it’s that drive to continuously challenge yourself that makes it different. (M2)
The comment above suggests that motivation is important for continuous learning. The notion that motivation is important for problem solving performance is also supported by the following comments:

Motivation is probably the biggest thing. (E7)

I think it’s deeply psychological, it’s deeply motivational. (E3)

Without the motivation and the determination, then forget it. (N2-6)

However, it is important to recognise that the participants are not referring to mere motivation. The data suggest something deeper than motivation. The participants also recognised that the key to developing problem solving skills is self-efficacy. The importance of self-efficacy for learning is also exemplified by a comment from one of the younger engineers with less than five years of industry experience:

Problem solving can be learnt but not taught. **The person needs to want to learn it.** (N2-3)

The engineers who participated in the survey were asked if they agreed or disagreed that good problem solving must be actively learned (Table 4.16). 73.2% of those surveyed strongly agreed or agreed that this must be the case.

Table 4.16: Survey responses on active learning and problem solving

<table>
<thead>
<tr>
<th>Good problem solving capability cannot be taught. It must be actively learned.</th>
<th>Frequency</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
<td>5</td>
<td>2.3</td>
</tr>
<tr>
<td>Disagree</td>
<td>24</td>
<td>11.3</td>
</tr>
<tr>
<td>Neither disagree nor agree</td>
<td>28</td>
<td>13.1</td>
</tr>
<tr>
<td>Agree</td>
<td>104</td>
<td>48.8</td>
</tr>
<tr>
<td>Strongly agree</td>
<td>52</td>
<td>24.4</td>
</tr>
</tbody>
</table>
The interview data also suggested that the participants believe that self-efficacy can drive a person’s ability and motivation to learn and to transfer the skills that they have learned from one problem to another (Figure 4.12).

The importance of self-efficacy for transferability was further supported by one of the senior engineers who said:

The biggest thing I’ve learned from my graduate studies... is not physics. The biggest thing... well two big things I’ve learned out of that... two big things that came out one that was one is the ability to think. And second because of the ability to think, a degree of confidence that you can solve any problems. And not just in physics but in anything else. Given enough time, and enough resources to read I’m confident I can solve anything. Not just in my personal live but in any other industry and domain. (E5)
The statement indicates that, apart from knowledge, the most important thing he gained from his time in formal education was confidence. Having that confidence has enabled him to face other types of problems in his life. This statement indicates that, for transferability to occur, self-efficacy is vital. An example of how the lack of self-efficacy can impact on the motivation to resolve future and current problems is indicated by the following statement:

Before the course I just look at a problem and like nah…I’m not going to be able to do that. It’s probably the key to my problem solving as well like if I don’t have the right the attitude towards it, I know it’s not going to happen… I’ve always had the attitude I’m not going to be able to do this. What am I going to do here? (N1-1)

The same participant explained that formally learning problem solving methodologies added to his confidence in resolving unknown problems:

After taking the problem solving course it’s easier to see if you tackle a problem from different angles that it makes them a lot easier and if you already got a pre-determined method on how to go about solving something it just makes it easier. (N1-1)

The statement above also indicates how methodologies and tools impact on problem solving performance. Being taught problem solving methodologies explicitly gave this participant confidence that he is able to resolve problems.

The importance of self-efficacy was also observed in the RGT responses (Table 4.17). Concepts that fall under this theme include the idea of the problem solver being someone who is ambitious, not content to stay where they are, someone who inspires others, a leader, hardworking and able to work independently. The ideal good problem solver should also have a positive attitude when it comes to challenges, have self-control and confidence, and be motivated.
Table 4.17: Self-efficacy theme in RGT data

<table>
<thead>
<tr>
<th>Theme</th>
<th>Sub-group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-efficacy</td>
<td>Personal ambition, future planning</td>
</tr>
<tr>
<td></td>
<td>Not simple/normal/bland/quiet/follower – has leadership qualities</td>
</tr>
<tr>
<td></td>
<td>Hard worker</td>
</tr>
<tr>
<td></td>
<td>Dependable/independent/reliable</td>
</tr>
<tr>
<td></td>
<td>Positive attitude/thinking</td>
</tr>
<tr>
<td></td>
<td>Self-control</td>
</tr>
<tr>
<td></td>
<td>Confidence</td>
</tr>
<tr>
<td></td>
<td>Motivated</td>
</tr>
</tbody>
</table>

4.4.2 Discussion

The value of reflection was identified by Adams (2010) in his research, although this concept was not fully explored in his study. As reported in Section 4.3, the expert engineers in this study suggested that evaluation and reflection is an important process in effective problem solving. The data presented in Section 4.3 also indicate that expertise and prior experience can increase bias and assumptions. The data reported in Section 4.4.1 show that evaluation and reflection is crucial to minimise bias and assumption. Similar to the concept of quick problem solving (Section 4.3), the data also shows that evaluation and reflection is perceived differently by the novices and the experts in the study.

Current literature suggests that the process of evaluation and reflection is well recognised as part of the problem solving process (Belski, 2002; Carlson & Bloom, 2005; Engineers Australia, 2009; Hambur, et al., 2002; Polya, 1945). However, this study found that younger engineers are not aware of the value of evaluation and reflection. Similar to the findings of Adams (2010), younger engineers (especially those without industry experience) rarely spoke about the concept of reflection in the interviews, unless prompted.
Further investigation revealed that younger engineers perceive the process of evaluation and reflection as a necessity only when mistakes are made, and thus it is solution driven. The data also suggest that younger engineers believe that the problem solving process is a linear process of understanding the problem, planning and implementation, followed by evaluation if necessary. This perception could be the result of the widely espoused theory of problem solving as a complete four steps of understanding the problem, planning, implementing and evaluation. Interestingly, when required to carry out evaluations, the younger engineers in Phase 1 of the study indicated that what they would evaluate would be their procedures. Borrowing concepts from Chi et al. (1982) and Gick (1986), it is proposed that younger engineers utilise a “working-backward” strategy for evaluation and reflection (Figure 4.13).

![Figure 4.13: Evaluation and reflection cycle in the perspective of young engineers in the research](image)

In contrast, senior engineers in the study believed that both procedures and assumptions need to be evaluated and reflected upon. The data suggest that the purpose of evaluation and reflection carried out by senior engineers in the study is the need to understand the problem better. It is proposed that when an expert problem solver engages in problem solving, he or she engages in repeated mini-cycles of the phases of understanding the problem, planning a solution, execution and evaluation. This suggests that problem solving is not linear but cyclic. It is posited that as problem solvers go through each cycle, they are improving their understanding of the problem, thus enabling them to come up with a more holistic solution. This suggestion corresponds with the findings of Carlson and Bloom (2005), who recognised that the problem solving process is cyclic. However, Carlson and Bloom (2005) proposed that when a solution does not fit the problem, the experts go back to the second stage of the problem solving process, the planning phase. In
contrast, in this study the experts explained that they go back to the first phase of problem solving, to understand the problem.

Interestingly, during the verification session, one of the experts (E3) suggested that solutions are often generated through the process of understanding the problem. This reiterates the theory of problem space (see Section 4.2.2) as suggested by Newell and Simon (1972). This also supports the suggestion that an understanding of the problem is crucial for problem solving. Again borrowing concepts from Chi et al. (1982) and Gick (1986), it is suggested that experts use a “working-forward” strategy when evaluating and reflecting (Figure 4.14).

![Figure 4.14: Evaluation and reflection cycle in the perspective of senior engineers in the research](image)

This difference can be accounted for by indications in the data that suggest that industry experience contributes to the understanding that solving problems requires a cyclic process. As previously mentioned, the types of problems faced in the workplace are significantly different from those of the university setting (Jonassen, et al., 2006). It can be proposed that exposure to real engineering problems conveys the realisation of the need to evaluate and reflect.

This proposal is supported by the data in the survey. It was found that when engineers in the research were surveyed about their problem evaluation habit, the majority reported on carrying out an evaluation process regardless of whether the solution was wrong or right (Table 4.12). However, when broken down into groups classified according their experience in the industry (Table 4.13), it was observed that the more years in the industry engineers have, the more likely they are to report that they always carry out an evaluation process. Thus, it is imperative that younger engineers should be trained in evaluation and reflection processes. As previously mentioned in Section 4.2.2, specific methodologies and tools that assist with problem
representation should be taught to young engineers. Similarly, younger engineers can be trained in specific problem solving tools that focus on evaluation and reflection.

Professional engineers are expected to be continuously learning to be able to cope with the challenges of the engineering role (Engineers Australia, 2009; Grasso, et al., 2004). Adams et al. (2010) suggested that learning problem solving skills can be facilitated by group work, project work, extensive practice using effective processes and methods, improving theoretical and practical knowledge, as well as creating a motivating learning environment. Interestingly, the engineers who were surveyed in this research were sceptical about the effectiveness of formal education on problem solving ability (Table 4.14). Even when surveyed on the effectiveness of industry experience on improving problem solving ability, barely half of those surveyed actually agreed or strongly agreed (Table 4.15). Participants in this study suggested that learning problem solving from life experience has been more valuable for developing their problem solving ability. This raises an interesting question: How is learning problem solving from life experience different from acquiring problem solving skills at a university? The data show that in real life, the problem solver is forced to consider and deal with consequences. Interestingly, younger engineers in the study mentioned that they only reflect when they made a mistake. Thus, the process of dealing with consequences forces younger engineers to engage more thoroughly in the process of evaluation and reflection.

The idea that reflection is inherently linked to learning was highlighted by Schön (1983), Moon (1999) and Jarvis (1992). Similarly, this concept was raised in the interview data. The interview data suggest that learning from a change of perception is important for transferability. As mentioned previously, problem identification is affected by problem solvers’ assumptions. Therefore, it is likely that a problem solver will be able to understand a problem better and solve it more effectively by changing his or her perceptions about it. This was supported by the participants who suggested that changes in the way they perceive a problem occur through continuous re-evaluation of their assumptions and knowledge. This process also helps with their problem solving skill development. This concept is supported by the research of Brockbank, McGill and Beech (2002), who suggested that double-loop reflection must be carried out for effective learning.
Brockbank, et al. (2002) made the distinction that learning through reflection can occur in two ways: i) in a single-loop of ii) in a double-loop. Single-loop learning involves reflection on a specific task and can result in “immediate improvement, [but] leaves underlying values and ways of seeing things unchanged” (p.10). On the other hand, double-loop learning occurs when assumptions are challenged, resulting in change of perception (Brockbank, et al., 2002). Brockbank, et. al. (2002) proposed that a paradigm shift can result in new knowledge.

Another difference between learning problem solving from everyday life and formal education is the prevalence of “options” for learners. “Options” refers to anything that gives learners opportunities to avoid challenges, in essence, enabling the problem solver to take the easy way out or solve a problem too quickly. Essentially, “options” reduces the need for a change of personal knowledge and assumptions.

The ability of a learner to propose answers quickly is often commended at university. The emphasis on getting a solution quickly can be misinterpreted by a learner to mean that understanding how he or she got the answer is not important. As discussed in Section 4.3, the misconception of quick problem solving as something positive does exist in the opinions of young engineers. Findings reported in Section 4.4.1 proposed that this misunderstanding can be detrimental to problem solving. Younger engineers who perceive getting an answer as the most important thing are more likely to utilise available “options”. When a problem solver gets to the right answer too quickly without really understanding the rationale behind the solution, schemata acquisition is hindered (Gick, 1986). It is proposed that this consequently inhibits transferability.

The possibility of an adverse impact of expertise on learning was also raised by the participants in our study. People learn from their past experiences. However, when expertise is achieved, the experts in this research reported the slowing down of learning due to over-saturation of knowledge. Another reason for this as suggested by the participants is the solidification of personality which increases resistance to change. This concept is supported by the observations of Atman et al. (1999). The senior students, more experienced in their research, were dismissive of alternative steps when resolving new problems. They were also critical of the prescribed steps, suggesting less flexibility than more junior students. These findings support the idea that prior experience and expertise may increase bias, as discussed in Section 4.3.
Kalyuga et al. (2003) suggested that as experience and expertise are developed, different strategies may be required for learning.

Similar to the findings of prior research (Adams, 2010; Dalrymple, et al., 2011; Mayer, 1998; Song & Grabowski, 2006), motivation is identified as a factor for problem solving performance. Kirwan (2009) proposed that motivation is important in his model for transferability. However, this study identified a higher level factor that impacts on motivation: self-efficacy, the self-belief of the problem solvers’ ability (Bandura, 1997). The interview data suggested that while problem solving methodologies can be taught, problem solving ability is learned. Two problem solvers can be taught the same methodology. Whether both are able to apply it in another context is dependent on the person’s willingness and ability to learn what was taught. This is verified by the survey data (Table 4.16). This is supported by Bandura (1997), who argued that self-efficacy “contributes to the acquisition of knowledge and development of subskills, as well as drawing upon them in the construction of new behaviour patterns… through the proactive exercise of efficacy belief in self-development, capacity is converted to capability” (p. 61). This concept is also supported by the findings of Pajares and Miller (1994), who observed in their study that self-efficacy is a good predictor of problem solving ability. The data in this study also suggest that methodologies and tools can contribute to higher self-efficacy. An engineer (N1-1) who did a formal problem solving course reported that learning about specific problem solving tools added to his confidence in resolving new problems (refer to p. 75).

Nonetheless, Bandura (1997) believed that despite having the skills and efficacy, a person may choose not to carry out the task required due to external conditions that reduce the need for action. This supports the finding that the presence of “options” can have a negative impact on transferability. As previously mentioned, “options” are conditions that inhibits the requirement to challenge current assumptions and knowledge. The evaluation and reflection process is required to develop self-efficacy as suggested by Bandura (1997):

Conception of skills serve as guides for developing competencies and as internal standards for improving them. Conceptions are rarely transformed into appropriate performances without error on initial attempts…observing one’s enactments provides the information needed to detect and correct mismatches.
between conception and action. If people do not monitor what they are doing, efforts to implement a good conception will not produce proficient action. (p. 26)

The statement above reiterates that learning from mistakes is vital for the development of problem solving skills. It also supports the suggestion that it is essential that young engineers are trained in evaluation and reflection processes.

Current literature has found evidence for the need to evaluate and reflect when resolving problems. However, this concept is rarely explored in depth. This study proposes that the value of evaluation and reflection is that it minimises existing assumptions and bias. This assists the problem solver to understand problems better. It has been identified that evaluation and reflection is perceived very differently by novice and expert engineers. This is important as the way evaluation and reflection is perceived impacts on the utilisation of this strategy. The results of this investigation have identified that a change of perception is important for transferable learning and that “options” are deterrents to a change of perception. While other studies have tended to suggest that motivation is an important factor, this research proposes that self-efficacy is more important for effective problem solving and learning. These additional factors are included in the overall model as shown in Figure 4.15.
Figure 4.15: Impact of strategies (evaluation and reflection) and personal qualities (self-efficacy) on performance and transfer
4.5 Role of peers and open-mindedness

4.5.1 Results

The role of peers was one of themes raised in the interviews. The interview data suggest that a good problem solver is someone who engages with others:

A good problem solver... it's in terms of how people engage with others. (M3)

One other participant also commented on the need to learn problem solving from others:

You learn not just from yourself but from what other people are doing. (M2)

These statements indicate that other people play a role in problem solving. The value of others when resolving problems was also demonstrated by the comments of one of the novice engineers:

You know how I said some people they are really wise...they know a lot of things that is happening around them. And so it's also about how you think oh that's actually related to something that I have heard or have seen before, or talked to people about before. [their brain has] lot's of connections. (N2-4)

The statement above suggests that the ability to get along with others allows the problem solver to gain new information and knowledge. The same concept was also observed in the RGT data (Table 4.18), where there is a suggestion that good problem solvers have characteristics that enable them to work well with others. The characteristics include being sociable, sharing knowledge and being kind to others.
Table 4.18: The role of peers in the RGT result

<table>
<thead>
<tr>
<th>Theme</th>
<th>Sub-group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to work well with others</td>
<td>Able to deal with others when working in groups</td>
</tr>
<tr>
<td></td>
<td>People orientated</td>
</tr>
<tr>
<td></td>
<td>Allows discussion</td>
</tr>
<tr>
<td></td>
<td>Not selfish</td>
</tr>
<tr>
<td></td>
<td>Trustworthy</td>
</tr>
</tbody>
</table>

The need to involve others in problem solving was also verified in the survey responses. Close to 90% of the engineers surveyed believed that speaking to others is important when resolving a problem (Table 4.19). Over 95% believed that input from others allows the problem solver to consider problems from different perspectives (Table 4.20).

Table 4.19: Survey responses on the importance of involving others during problem solving

<table>
<thead>
<tr>
<th>It is important to talk to others when solving a problem as everyone can contribute one way or another to a problem resolution.</th>
<th>Frequency</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
<td>2</td>
<td>0.9</td>
</tr>
<tr>
<td>Disagree</td>
<td>5</td>
<td>2.3</td>
</tr>
<tr>
<td>Neither disagree nor agree</td>
<td>17</td>
<td>8.0</td>
</tr>
<tr>
<td>Agree</td>
<td>122</td>
<td>57.3</td>
</tr>
<tr>
<td>Strongly agree</td>
<td>67</td>
<td>31.5</td>
</tr>
</tbody>
</table>
Table 4.20: Survey responses on understanding different perspectives of a problem through discussions with others

<table>
<thead>
<tr>
<th>Having discussions with others allows a problem solver to understand different perspectives of the problem that he/she may be facing.</th>
<th>Frequency</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Disagree</td>
<td>3</td>
<td>1.4</td>
</tr>
<tr>
<td>Neither disagree or agree</td>
<td>5</td>
<td>2.3</td>
</tr>
<tr>
<td>Agree</td>
<td>98</td>
<td>46.0</td>
</tr>
<tr>
<td>Strongly agree</td>
<td>106</td>
<td>49.8</td>
</tr>
</tbody>
</table>

While both groups raised the concept of the role of other people in problem solving, again a difference of opinion was observed between the younger and senior engineers. Younger engineers in the research tended to see the role of other people as a source of help. This is exemplified by the comments of novice engineers:

We did a research but still have no solutions. That is the time when we have to seek for an advice. (N1-6)

During the programming course it was always frustrating when you get stuck in a project. You don’t know what to do to solve the problem…first of all just keep trying with the program…plus you have to read some book and also ask some people to help you. (N1-4)

In contrast, the senior engineers in our research perceived the value of speaking to other people as a means of understanding the problem from different perspectives:

How you gained understanding [of a problem]… You are probably going to talk to a lot of people. (E1)

An exchange of discussion with friends or somebody who is like-minded, speeds up this evolution of thinking. Back and forth and you might come up with an idea but somebody else might say it’s not going to work because of this. Because your thinking is not going in that path. So two people there is this back
and forth exchange and it's very dynamic and fast. Sometimes one brain can get stuck on a single path and may not look at the space tangent to it. But the other person obviously, not being you can think in a different line and sometimes….in other words exploration of problem space is now doubled with two brains… you’ve got exploration of a wider space. (E5)

The above comment reaffirms that discussion can result in a wider consideration of the problem and this assists with a holistic view of the problem. It is summarised in Table 4.21 that novice engineers perceive the role of others as “help” and are more likely to involve others after trying to resolve the problem on their own. In contrast, senior engineers in the study perceive others as a source of dialogue and are more likely to involve others even before trying to resolve the problem on their own.

Table 4.21: Summary of the difference of opinions between novice and expert engineers on the role of peers when resolving problems

<table>
<thead>
<tr>
<th>Novice</th>
<th>Theme</th>
<th>Expert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus on: Perceive others as a source of “help”. More likely to try the problem on their own first, before involving others.</td>
<td>Role of peers</td>
<td>Focus on: Sees others as a source of dialogue. More likely to involve others even prior to attempting the problem on their own.</td>
</tr>
</tbody>
</table>

The suggestion derived from the interview data was confirmed by the survey data (Table 4.22). To investigate whether different groups of engineers perceive the role of other people differently, the survey included the following question: When facing a problem, people should only ask for help AFTER they have tried to resolve it on their own. It was observed that 63.6% of N1 and 62.5% of N2 agreed with the statement that people should only be asked for help AFTER they have tried to resolve it on their own. In contrast, only 36% of the mid-level engineers (M) surveyed agreed with this statement and only 32.1% of the expert engineers (E) agreed with this statement.
Table 4.22: Survey response on when other people should be involved when resolving problems

<table>
<thead>
<tr>
<th>Industry Experience</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neither disagree nor agree</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>no industry experience (N1)</td>
<td>8</td>
<td>16</td>
<td>8</td>
<td>39</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>9.1%</td>
<td>18.2%</td>
<td>9.1%</td>
<td>44.3%</td>
<td>19.3%</td>
</tr>
<tr>
<td>less than 5 years industry experience (N2)</td>
<td>4</td>
<td>13</td>
<td>10</td>
<td>31</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>5.6%</td>
<td>18.1%</td>
<td>13.9%</td>
<td>43.1%</td>
<td>19.4%</td>
</tr>
<tr>
<td>6-10 years industry experience (M)</td>
<td>1</td>
<td>10</td>
<td>5</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>4.0%</td>
<td>40.0%</td>
<td>20.0%</td>
<td>32.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>more than 10 years industry experience (E)</td>
<td>2</td>
<td>13</td>
<td>4</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>7.1%</td>
<td>46.4%</td>
<td>14.3%</td>
<td>25.0%</td>
<td>7.1%</td>
</tr>
</tbody>
</table>

Using the Kruskal-Wallis Test, it was found that there was statistical significance in the responses in the different groups (p<0.01). Further testing using the Mann-Whitney U-Test found statistical significance when novice groups (N1 and N2) were compared with the mid-level and the expert groups (Table 4.27). The data suggest that the more industry experience an engineer has, the less likely he or she is to agree with the statement.
Table 4.23: Statistical analysis on group comparisons on when other people should be involved when resolving problems

<table>
<thead>
<tr>
<th>Comparison group</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1 – N2</td>
<td>0.869</td>
</tr>
<tr>
<td>N1 – M</td>
<td>0.027*</td>
</tr>
<tr>
<td>N1 – E</td>
<td>0.010*</td>
</tr>
<tr>
<td>N2 – M</td>
<td>0.016*</td>
</tr>
<tr>
<td>N2 – E</td>
<td>0.005*</td>
</tr>
<tr>
<td>M - E</td>
<td>0.597</td>
</tr>
</tbody>
</table>

*Statistical significance is observed (p<0.05 or p<0.01).

There is also an indication in the interview data that the concept of the role of other people is linked strongly to the idea of open-mindedness:

Be prepared for anything that may come up… be open-minded. In terms of problem solving skill, it doesn’t always mean you are a good thinker or what. It’s just about how you put things together. Because people have different thinking skills… you get different ideas, from different people and try to put them together. (N2-1)

[When solving a problem] you can’t put yourself in a cube… two brains are so much better than one brain. (N1-3)

One of the senior engineers interviewed also stressed the importance of open-mindedness to ensure proper problem diagnosis:

You may set to solve what you perceived to be an important problem and be missing even bigger problems which is right next to it, and may be even more important to get ontop of. It’s being flexible enough to not get stuck on things. (E6)

Open-mindedness was also a theme that was raised in the RGT data (Table 4.24). This concept includes the idea of accepting the perception of others and not being stuck in one’s way.
Table 4.24: Open-minded theme raised in the RGT data

<table>
<thead>
<tr>
<th>Theme</th>
<th>Sub-group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-mindedness</td>
<td>Accepting other people’s opinion, viewpoints, ideas</td>
</tr>
<tr>
<td></td>
<td>Open minded</td>
</tr>
<tr>
<td></td>
<td>Suggestions of flexibility</td>
</tr>
</tbody>
</table>

It is no surprise that expert engineers if not open-minded may be biased when resolving problems. This is exemplified by this statement from one of the mid-level engineers who was interviewed:

> When **people get too set in their own ways or think that they are able to solve the problem themselves**, I noticed these people don’t engage with others as much and possibly **cut off potential solutions** because they’ve got these thought process that they know best. And not a lot of time and most of the people don’t actually know best. And this is myself included, when I’m set in one direction I actually would cut off potentially good solutions. So really good problem solvers take feedback from others. (M3)

The statement above suggests that a lack of open-mindedness may result in non-creative outcomes when resolving problems. This was further supported by a comment from one of the senior engineers who was interviewed:

> The ego has to go away and then I think you can be very creative. (E1)

Creativity was identified in the RGT data as a valued characteristic of a good problem solver. One of the senior engineers suggested that creativity can be brought about by experience:

> I think where you **have a lot of experience** you have…**you can see a lot more of possibilities** to be more creative. (E3)

However, it was interesting that conservatism was linked to experience by one of the senior engineers interviewed:
If the problem is critical and would involve a lot of danger to lives, then I’ll go with the conservative ones. Sometimes these young guys would try to experiment on a lot of things even though it hasn't been proven. Even though it is not a proven concept they’ll still try to experiment on it, then I won’t go for a new guy. I’ll go for an experienced one. (E2)

The impact of expertise on creativity was further explored in the survey phase of the research (Table 4.25). In the survey, only 19.5% of the engineers surveyed agreed or strongly agreed that an expert engineer is more likely to come up with more creative solutions than an inexperienced engineer.

Table 4.25: Survey responses on the impact of expertise on creativity

<table>
<thead>
<tr>
<th>An expert engineer is more likely to come up with creative solutions compared to a younger, inexperienced engineer.</th>
<th>Frequency</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly disagree</td>
<td>10</td>
<td>4.8</td>
</tr>
<tr>
<td>Disagree</td>
<td>78</td>
<td>37.1</td>
</tr>
<tr>
<td>Neither disagree nor agree</td>
<td>81</td>
<td>38.6</td>
</tr>
<tr>
<td>Agree</td>
<td>36</td>
<td>17.1</td>
</tr>
<tr>
<td>Strongly agree</td>
<td>5</td>
<td>2.4</td>
</tr>
</tbody>
</table>

4.5.2 Discussion

The role of peers in problem solving was identified by both the professionals and the novices in the research of Adams et al. (2009; 2010), who suggested that knowledge networking (Allen & Long, 2009) is a crucial aspect of problem solving. This has been similarly observed in this study. Adams (2010) proposed that group work is important in the development of problem solving skills. Hadgraft and Muir (2003) also suggested that the ability to work with others is one of the skills that engineers should have.
This research delved deeper into the theme and discovered that the role of others in problem solving is perceived differently by young and expert engineers. As discussed in Section 4.4.2, perceptions of a particular strategy impact on the effectiveness of the strategy on problem solving performance and transferability.

Younger engineers in the research tended to consider peers as a source of help when solving problems. For this reason, they believed that other people should only be involved in the problem solving process if the problem solver is unable to resolve the problem on his or her own. On the other hand, expert engineers in the research perceived others as a source of dialogue to get a better understanding of the problem space. This difference of opinion was evident in both the interview data and the survey data.

When the role of others is perceived as help, this can be detrimental to transferability as this strategy becomes an “option” (refer to Section 4.4). Considering the role of other people as a source of help negates the need to really understand the rationale behind the answer when solving a problem. Getting help may result in a problem being solved, but unless the learner understands how and why the answer is an ideal solution, the learner is unlikely to be able to apply it in a new context without more help from other people.

In education, strategies such as working in groups are highly encouraged. While working in groups helps novices to develop their communication skills, it can become a deterrent to the development of transferable problem solving ability when engineers become too dependent on the help of other people. For example, one of the participants (N1-2) stated that his problem solving strategy is to ask other people (refer to Section 4.4.1, p. 71). He clearly mentioned that he does not feel the need to learn when he can ask someone else. He also indicated that while he did well in areas where he got help, he did not do well in areas where he had to apply knowledge on his own. This example indicates the lack of transfer due to an “option”.

This idea is supported by a recent study of Steiner et al. (2011). Students in their survey reported that group work is one of the least helpful methods of developing problem solving skills. Therefore, it is imperative to ensure that any group work addresses the misconception that young engineers may have about the value of the process. Based on the results of this research, it is proposed that the value of working with others is that it enables the problem solver to increase the problem
space (Figure 4.16). As discussed in Section 4.3, personal assumptions shape a person’s understanding of the problem. An understanding of the depth of the problem can be enhanced through conversations with others. This enables the problem solver to consider the problem holistically.

![Figure 4.16: The value of working with others](image)

Understanding the problem from the problem solver’s perspective

Perspective of the problem increases after dialogue with others

The data also suggest that working with others enables the problem solver to build on his or her existing knowledge and assumptions. As identified in Section 4.4, for transferability to be achieved, engineers need to have their assumption and knowledge challenged. It can be proposed that discussion with others allows the dynamic building of schemata, creating new knowledge and information.

The value of involving others when resolving problems is linked to the concept of open-mindedness, which is identified as an important personal quality. The value of open-mindedness for the problem solving process was identified by Adams (2010) but was not fully explored. This research has identified that open-mindedness is crucial for the strategy of working with others to be successful. The data suggest that an open-minded problem solver is more likely to consider more aspects of a problem, thus carrying out better problem representation, and is more likely to come up with more solution options. With open-mindedness, a problem solver is more capable of considering problems as a whole system without being bounded by his or her prior experiences.

In this study, it has also been observed that the idea of open-mindedness is related to the concept of creativity. The data suggest that open-mindedness is required to
achieve creative outcomes. This idea is also supported by the literature of Amabile (1983). In her model of components of creative performance, she proposed that creativity-relevant skills are required. These skills include abilities to “break perceptual set” and “explore new cognitive pathways” (Amabile, 1983, p. 364). Essentially, the skills she considered creative cognitive abilities are linked with being open-minded.

Amabile (1983) also proposed that domain-relevant skills are required for creative problem solving. Similarly, the data in this research suggest that gaining expertise can result in creativity. However, in this study a possible negative impact of expertise on creativity was also found. The notion that expertise may increase conservatism when resolving new problems was evident in the interview and survey data. The findings reinforce the idea that expertise does not always ensure better problem solving performance. This supports the idea that expertise may increase bias and assumptions (see Sections 4.3 and 4.4).

Unlike existing literature, this study has investigated in depth the concept of working with others when resolving problems. It was found that the value of working with others is that it contributes to the understanding of the problem and transferability. This study has identified that how a strategy is perceived can impact on the effectiveness of the strategy. While creativity is observed as a factor for problem solving performance, it is also identified that open-mindedness can compel creativity. Therefore, open-mindedness is identified as a crucial personal factor for successful problem solving. These factors complete the final model as seen in Figure 4.17.
Figure 4.17: Strategies and personal qualities that assist with overcoming assumptions that impact on the understanding of the problem.
4.6 Summary of key findings

Based on the results and discussions, the key findings in this study are:

1. The key to good engineering problem solving is the ability to understand the problem fully before resolving it.

2. There is a misconception that quick problem solving is good problem solving, especially in the opinions of young engineers.

3. Expertise may have adverse impact on problem solving performance, especially for novel problems.

4. Specific strategies used to minimise the effect of personal assumptions are important; they are: (1) the role of peers and (2) evaluation and reflection.

5. Personal qualities that impact on performance and transferability are open-mindedness and self-efficacy.

6. “Options” impact on the transfer of problem solving ability.

In each of the discussion sections of this chapter, a model is introduced and built upon. The final developed model is discussed in the next chapter.
Chapter 5: Model and Recommendations

5.1 A new proposed model for engineering problem solving

Figure 5.1: Problem solving and transferability model proposed in this study
The proposed model (Figure 5.1) suggests two main goals for engineering problem solving:

1. Holistic problem solving (performance outcome)
2. Transferability to other areas

The model covers the following factors:
- the skill that is required (understanding of the problem)
- strategies (the role of peers as well as evaluation and reflection)
- personal qualities (self-efficacy and open-mindedness)
- detrimental aspects (misconception of the value of quickness, focus on problem solution, assumptions about expertise and "options")

The model suggests that performance is driven by the ability to understand the problem well. This forms the core of the model. This study suggests that this is the skill aspect that needs to be well developed by engineers. Methodology or tools are the media that enable a problem solver to carry out the process of understanding the problems well. Thus, it is imperative that young engineers are taught tools that assist them with problem analysis and definition.

The ability to understand a problem is affected by the personal assumptions of the problem solver. While prior experience and expertise can assist a problem solver to recognise problems faster, they also increase bias and assumptions. When it comes to facing new problems, strategies that assist with overcoming bias and assumption become crucial. The two main strategies identified are engaging with peers and the process of evaluation and reflection. However, it is important to recognise that how these strategies are perceived can impact on their utilisation and the overall outcome.

Evaluation and reflection can take two approaches: working backward and working forward (Figure 5.2). In the working-backward strategy, evaluation and reflection is carried out only when the solution does not fit the problem and it relates to the correction of process only. This approach focuses on problem solutions. The ideal use of evaluation and reflection is the working-forward approach. This approach is driven by the need to better understand the problem and thus it focuses on problem analysis. This approach requires the correction of both process and assumptions. It also encourages transferability as the correction of assumptions is carried out.
Methodologies and tools (as indicated in Figure 5.1) can be used to train younger engineers in the process of evaluation and reflection.

Similarly, the role of peers can also have two approaches: as help or as a source of dialogue (Figure 5.3). Perceiving others as a source of help focuses on problem solution and provides a means of “options”, which was identified as diminishing transferability. On the other hand, perceiving others as a source of dialogue enables a problem solver to consider all aspects of the problem and focuses on problem analysis. Transferability is also encouraged, as through dialogue with others the understanding of knowledge and perceptions are challenged.
The possibility that the strategies can be utilised in two ways highlights the importance of addressing misconceptions such as quickness in problem solving and focus on problem solutions. The main model (Figure 5.1) acknowledges that personal qualities such as self-efficacy and open-mindedness are required for effective problem solving and transferability. Personal qualities and strategies are linked. To increase self-efficacy, the problem solver needs to engage in the process of evaluation and reflection. For effective utilisation of the role of peers, the problem solver needs to be open-minded. Knowing specific problem solving methodologies and tools can also boost self-efficacy when facing new problems. The model also suggests that “options” need to be minimised as they reduce the need for the problem solver to learn, negating transferability.

5.2 Implications for practice: recommendations

Based on the model suggested in Section 5.1, for effective deployment of formal education and training in problem solving, the following should be addressed:

1. The course should improve students’ ability to understand problems systematically and fully. Therefore, training should focus on strategies and tools that assist with problem analysis.

2. Young engineers should be trained to develop the habit of evaluating and reflecting.

3. The course should address misconceptions such as quickness in problem solving and the focus on solutions.

4. “Options” should be minimised.

5. The course design needs to take into consideration how open-mindedness and self-efficacy can be enhanced.

6. Continuous training even for experts needs to be considered.

The findings and models in this study also suggest that a number of factors can be used as measurements of performance and transferability. Using the suggestions of Nusche (2008), both cognitive and non-cognitive aspects are considered. It is suggested that the following can be measurable indicators:
1. Ability to understand the problem well (cognitive skill)

2. Open-mindedness (non-cognitive factor)

3. Self-efficacy (non-cognitive factor)

The research has identified that the most important cognitive skill for effective problem solving is the ability to understand the problem well. Since it is recommended that courses should develop students’ ability to understand problems systematically and fully, it makes sense that this is a factor that should be measured. Increased performance in this aspect may indicate ability to resolve problems efficiently. This study has also found that non-cognitive factors such as open-mindedness and self-efficacy are vital for successful problem solving and transferability. Open-mindedness indicates the problem solver is able to consider problems even beyond his or her personal bias. This process will assist the problem solver even when facing new problems. Self-efficacy also encourages transferability as it is vital for long-term learning. It also gives the problem solver confidence even when facing unknown problems. It is believed that these three factors can be used to measure performance and the likelihood of transfer. These three factors simplify the measurement process and suggest a standardisation of factors that can be measured.
Chapter 6: Conclusion and Future Research

6.1 Conclusion

The aim of education is to equip graduating students with specific skills that will enhance their employability. The uniqueness and value of engineering education is its focus on developing the problem solving skills of engineers. It is imperative to investigate how engineering educators can ensure that courses improve students’ problem solving ability. Proper evaluations need to be carried out to ensure that courses are effective for the development of problem solving performance. These processes are currently informed by literature that is not fully representative of the nature of engineering problems.

This research has focused on the engineering perspective of problem solving and answers the following research questions:

- What do engineers perceive to be aspects of good problem solving?

It was found that engineers in the research perceive holistic problem solving as the aim of engineering problem solving. In order to do this, an understanding of the problem is the key factor of good problem solving.

- What factors are the most vital for problem solving performance and transferability?

Other than understanding the problem, factors that assist with overcoming bias and assumptions are very important for performance. Strategies such as the use of others’ knowledge as well as evaluation and reflection are identified as important. However, the approach utilised in these strategies can impact on performance and transferability. Transferability is encouraged through the constant questioning of personal assumptions and knowledge. Personal qualities such as self-efficacy and open-mindedness are required to ensure performance and transfer are achieved. This research has also identified factors such as misunderstanding quick problem solving, a focus on solutions, and “options” as detrimental for performance and transfer. Although expertise is perceived as positive, it can also have an adverse impact when facing new problems.
6.2 Contributions to theory

Findings in the study contribute to theory through the following:

1. Understanding the problem solving process better from the perspective of engineers.

2. Investigating what factors impact on problem solving performance with transferability into new problems being taken into account.
   a. Showing that factors are linked and not independent of each other.
   b. Identifying key factors that truly impact on performance:
      i. Understanding the problem
      ii. Factors that assist with negating bias and assumptions:
          1) Evaluation and reflection
          2) Engaging others
      iii. Personal qualities:
          1) Self-efficacy
          2) Open-mindedness
   c. Not just showing factors that influence positively but also factors that have a detrimental effect on performance and transferability:
      i. Prior experience and expertise not always positive when facing new problems.
      ii. Misconceptions:
          1) Quick problem solving
          2) Focus on generating solutions
      iii. “Options”

3. Identifying a set of factors that can be used to develop standards for measuring problem solving performance.
   a. Simplified factors, covering both cognitive and non-cognitive aspects:
      i. Problem analysis (skill)
      ii. Self-efficacy (personal quality)
      iii. Open-mindedness (personal quality)
6.3 Future research

The data that were collected through the three methods described in the methodology are rich and in-depth. For the purpose of this study, analyses were carried out specific to the research objectives and questions. The rich data also yielded other valuable information pertaining to engineering education. However, these data have not been fully explored. The RGT also provided a set of quantitative data (as indicated in Section 3.4) which was not included in the analysis of this study. Further analysis of these sets of data may provide valuable information for engineering education in general.

This research used non-probability sampling (see Section 3.2), which is driven by the methods employed. It is important to recognise that the findings in this research are only representative of the engineers who participated in the research, and not generalisable to the whole population. Nonetheless, the views do exist and these observations are useful for understanding the problem solving process from the perspective of engineers. It would be worthwhile for future research to further test these findings in experimental settings as well as in the full engineering population.

A number of suggestions have been made in this study to improve the formal training of engineers. Future research should focus on investigating how these recommendations could be implemented. Future research could also focus on how a proper evaluation mechanism can be developed and implemented to measure the effectiveness of problem solving training.
References


Engineers Australia. (2009). Australian Engineering Competency Standards - Stage 1 Competency Standards For Professional Engineers Canberra.


Appendices

Appendix A – Interview Questions

Interview for participant who has taken a problem solving course:

What do you think is problem solving skills?
- Do you think is important to solve problems?
- An example of a person with problem solving skills?

What you think is the most important aspect of good problem solving?
- Eg. Is it attitude?

Do you think problem solving can be learnt?
- How do you feel it can be learnt or taught?
- An example of how you’ve learnt it or taught it to others.

If it can be learnt or taught, do you feel it is transferable?
- Why?
- An example of where you feel this is evident.

This about current measures of measuring problem solving capacity, do you feel it is sufficient?
- What is good about it?
- What is lacking in it?

If you are to be measured on your problem solving, how would you like to be tested?
- Shall it be measured by the process of problem solving?
- Shall it be measured on end outcome?

About you:

Think back about 1 year ago, how do you solve problems that you’ve faced?
- Situation, Tasks, Action, Results
- Why do you think you do/think that?
- What was your attitude?
- Give an example.
- What do you think made you react that way?

Tell me the reasons why you decided to do a problem solving course?
- What made you want to take it?
- Do you feel that the ability to solve problems is very important?
- How so?

What have you learnt in the course?
- What was important?
- What can be improved?

Think about a recent problem, how did you resolve it?
- What do you think is the changes you have experienced through the course that will help you or not help you?
- Which aspects is the most important?

Have you been able to apply what you have learnt to a real life problem?
- An example?
- How about in other courses?

Interview for participant who may not or may have taken a problem solving course:

What do you think is problem solving skills?
- Do you think is important to solve problems?
- An example of a person with problem solving skills?

What you think is the most important aspect of good problem solving?
- Eg. Is it attitude?

Do you think problem solving can be learnt?
- How do you feel it can be learnt or taught?
- An example of how you’ve learnt it or taught it to others.

If it can be learnt or taught, do you feel it is transferable?
- Why?
- An example of where you feel this is evident.
This about current measures of measuring problem solving capacity, do you feel it is sufficient?
- What is good about it?
- What is lacking in it?

If you are to be measured on your problem solving, how would you like to be tested?
- Shall it be measured by the process of problem solving?
- Shall it be measured on end outcome?

About you:

Think back about 2 years ago, how do you solve problems that you’ve faced?
- Situation, Tasks, Action, Results
- Why do you think you do/think that?
- What was your attitude?
- Give an example.
- What do you think made you react that way?

Think about a recent problem, how did you resolve it?
- Are there any changes as to how you think, or your attitude towards that problem?
- Why has it changed if any?
- Which aspects of the change is the most important?

Did you take (or had a chance to take) a thinking and problem solving course?

Tell me the reasons why you decided (or not decided) to do thinking and problem solving course?
- What made you want (or not want) to take it?
- Do you feel that the ability to solve problems is very important?
- How so?

If you had taken a course, have you been able to apply what you have learnt to a real life problem?
- An example?
- How about in other courses?
Appendix B – Examples of the use of memos, diagrams and journal

Examples of memos

<table>
<thead>
<tr>
<th>Example 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘[The issue with people who don’t solve problems well] is I think some people jump to conclusions too quickly. And therefore going back to what I said before, it then cuts off a whole part of information that they should probably be considering. Um…what else? Yes. The jumping to conclusion, the just making decisions, or coming to conclusions too quickly as well.’ (F, 30-34, 10 years – M3)</td>
</tr>
<tr>
<td>This statement is an example of what the participant perceive to be bad problem solving. Interestingly it’s jumping to conclusion &lt;-- assumptions. And the coming to conclusions quickly &lt;-- which young novice engineers sometimes perceive as ”good problem solving”.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Example 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Like for example, even if they have the same qualification but they don’t have, what I mean the way they attack, the approach is not so the same. So even if they have the same qualification then we also need to consider the manner that they approach the problem.’ (M, 40+, more than 10 – E2)</td>
</tr>
<tr>
<td>I actually found this comment interesting. The thing that kept coming up is the approach...ie. How did the person perceive the problem. Participants 161210, 151210, 101210 talked about the way the ’mind works’ when evaluating ability to solve problems. Again, this idea that everyone has different understanding, or perhaps different assumptions.</td>
</tr>
</tbody>
</table>
Example 3

'I guess the way I see a problem. If I look at my brother and myself we just have very different minds.' (F, 35-39, 2 years, N2-6)

I asked her if she felt there were differences with how different genders solve problems. I found it interesting she talked not about process, but about the perception aspects. I'm not agreeing or disagreeing that one gender solves problems better but I found it interesting she attributed the differences on solving problems as the way someone sees things. **This emphasises the idea of how problem representation is inherently affected by assumptions.**
Examples of the use of diagrams

Example 1

This model was created based on initial analysis. It was found that the responses suggest that problem solving is driven by motivation. However, the problem relies on his own personal knowledge and then engages others to tap into external knowledge repository. This is done to supplement their knowledge to resolve the problem. This process only undertaken AFTER tapping into personal knowledge database.

Later realised that this model does not fit the processes undertaken by senior engineers. This model is only applicable for younger engineers (ie. Perceive others as source of help). Perhaps this is also because I am a younger person? Hence, I had this misconception myself?
Example 2

The model above suggests that good problem solving is the ability to resolve problems as a whole. Three main factors were identified: motivation, methodology and open-mindedness. Also recognition that problem solving is to do with a viewpoint. Self-reflection is included, but wonder if this is because of my own background working on projects that evaluate the effectiveness of self-reflection tools?

Carried out selective coding and found that this model is not accurate. Methodology is really not a “main” theme. Also self-reflection rarely mentioned by younger engineers. So maybe reflection is not important?
Example 3

This model suggests that the aim of engineering problem solving is to resolve problems holistically. To do this the problem solver needs to understand the problem. This process is affected by personal assumptions, so open-mindedness is required. Motivation is now elevated to “self-efficacy”. Self-efficacy drives transfer and also assist with problem solving. Methodology helps with problem identification. It can also assist with process of open-mindedness and self-efficacy. The impact of “options” is also established.

Need to do selective coding to find evidence to prove or disprove this model.
Further analysis showed that there is something else going on in regards to transfer. When knowledge and assumption is constantly evaluated (concepts of learning from mistakes), then transfer occurs. This process contributes to new understanding of knowledge. In the data, initially evaluation and reflection were considered as not important as initially published in 2010 paper. But actually after interviewing more senior engineers, realised they do stress the importance of evaluation and reflection. Maybe this process is important after all? Go back to transcripts and see if there is any evidence of why this is important? Maybe compare responses of novice and expert engineers? See if other themes show other contrary “evidence”.

---

**Example 4**

- self-efficacy
  - drives
    - more “sticky”
  - transferability
    - diminishes
      - understanding of knowledge, the ‘why’
        - why did I do that?
        - why did I choose to use this solution?
        - why did I go wrong here?
        (challenging personal assumptions and knowledge)
      - ‘options’
        - eg. external help, way out, or anything that takes away the need to solve the problem, the need to learn
Examples of personal journal

Example 1

Example 2
Example 3

Role of knowledge: we don’t always have all the knowledge.
- we don’t always use all the knowledge we have.

Agreement that a test that works 
precedes + outcome but

Complex problem solving strategies
- cannot be used due to role, experience, etc.

Engineering as problem solving affects lives:
- if needed to solve life's death problem
  go to more experience, traditional approach.
- new ideas if does not impact-life (experimentation)
Appendix C – Online Survey Questions

Innovative Problem Solving for Engineers: Measures for Transferability

Project Title:
Innovative Problem Solving for Engineers: Measures for Transferability

Investigators:
Ms Jennifer Harlis (School of Electrical & Computer Engineering PhD Candidate, jennifer.harlis@rmit.edu.au, 99258947)
Dr Iouri Beliski (Project Supervisor: Professor, School of Electrical & Computer Engineering, RMIT University, iouri.beliski@rmit.edu.au, 99252844)

This project has received clearance by the Human Resource Ethics Committee (HREC No. BSETAPP92).

Dear Participant,

You are invited to participate in a PhD research into the area of developing a measure for transferability of problem solving skills in the engineering field.

In the engineering education, the students are expected to have the ability to solve problems efficiently. This study sought to clarify what are the factors that contribute to one’s ability to solve problems well. The results will be used to develop a measure of the transferability of problem solving skills. Between 2009 and 2011 interviews were conducted to investigate the following research questions:

- What are the factors that contribute to good problem solving process?
- How do engineers go about learning problem solving for transferability?

The questionnaires that you have been asked to participate in is the last stage of data collection for this study. There is no right or wrong answer in the survey. It is more important that you answer as honestly as possible. The purpose of this final data collection is to ensure validity within the data gained from the initial interview stage.

This anonymous survey will only take between 5-10 minutes of your time. Your participation in this survey is strictly voluntary.

If you would like to read the full details of the study before deciding to participate, please indicate below with “yes” and click Next. If you would like to participate immediately, click Next to continue.

1. Would you like to read the full details of this study?

☐ Yes
Innovative Problem Solving for Engineers: Measures for Transferability

Plain Language Statement

Dear Participant,

You are invited to participate in a research project being conducted by RMIT University. This information sheet describes the project in straightforward language, or plain English. Please read this information carefully and be confident that you understand its content before deciding whether to participate.

Project Title:
Innovative Problem Solving for Engineers: Measures for Transferability

Investigators:
Ms Jennifer Harlin (School of Electrical & Computer Engineering PhD Candidate, jennifer.harlin@rmit.edu.au, 00250947)
Dr Iouri Debats (Project Supervisor: Professor, School of Electrical & Computer Engineering, RMIT University, iouri.debats@rmit.edu.au, +61 03 9925 9894)

This research is for the obtaining of a Doctor of Philosophy (PhD) degree. This project has received clearance by the Human Resource Ethics Committee (HREC No. BSETAPP93).

Why have you been approached?
You have been approached if you fulfil one or more of the following criteria:
- A student who is currently enrolled in an engineering course.
- A student who has completed an engineering course and is currently looking for employment within the field.
- A professional working within the engineering field.
- A member of the academic staff who teaches engineering.

What is the project about? What are the questions being addressed?
This project is a 4-year PhD research into the area of developing a measure for transferability of problem solving skills in the engineering field. In the engineering education, the students are expected to have the ability to solve problems efficiently. This study sought to identify what are the factors that contribute to one’s ability to solve problems well. The results will be used to develop a measure of the transferability of problem solving skills. Between 2009 and 2011 interviews were conducted to investigate the following research questions:

- What are the factors that contribute to good problem solving processes?
- How do engineers go about learning problem solving for transferability?

The questionnaire that you have been asked to participate in is the last stage of data collection for this study. The purpose of this final data collection is to ensure validity within the data gained from the initial interview stage.

If I agree to participate, what will I be required to do?
Your participation will involve an online web-based survey. This anonymous survey will only take between 6-10 minutes of your time.

What are the risks or disadvantages associated with participation?
By participating in the anonymous survey, Risk Level 1 which refers to non-invasive projects where there is no apparent risk to participants above the everyday norm and where participants are not identified is associated. If you are unsure about the nature of personal information that is collected, you should review the RMIT University Human Research Ethics Committee (HREC) Guidelines (please visit: www.hrec.rmit.edu.au).
Innovative Problem Solving for Engineers: Measures for Transferability

What are the benefits associated with participation?
Participants will benefit as a through proper measurement, better courses can be designed. This will ensure students will receive better quality courses which may lead to higher employability. Professional engineers will benefit as the study may lead to better graduating engineers who will join the workforce. Academic staff may use the results to design better courses that will improve their students outcomes.

What happens to the information I provide?
The data collected will be used for the thesis and the results may appear in publications. The results will be reported in a manner which does not enable you to be identified. Thus, the reporting will protect your anonymity. Any information that you provide can be disclosed only if (1) it is to protect you or others from harm, (2) a court order is produced, or (3) you provide the researchers with written permission. The research data will be kept securely at RMIT for a period of 5 years before being destroyed.

Security of the website
Users should be aware that the World Wide Web is an insecure public network that gives rise to the potential risk that a user's transactions are being viewed, intercepted or modified by third parties or that data which the user downloads may contain computer viruses or other defects.

Security of the data
This project will use an external site to create, collect and analyse data collected in a survey format. The site we are using is Survey Monkey. If you agree to participate in this survey, the responses you provide to the survey will be stored on a host server that is used by Survey Monkey. No personal information will be collected in the survey so none will be stored as data. Once we have completed our data collection and analysis, we will import the data we collect to the RMIT server where it will be stored securely for a period of five (5) years. The data on the Survey Monkey host server will then be deleted and archived.

What are my rights as a participant?
As a participant, you have:
- The right to withdraw your participation at any time, without prejudice.
- The right to have any unprocessed data withdrawn and destroyed, provided it can be reliably identified, and provided that doing so does not increase the risk for the participant.
- The right to have any questions answered at any time.

Where should I contact if I have any questions?
If you have any questions or concerns regarding this project, feel free to contact me at jennifer.harlin@rmit.edu.au or my supervisor Dr. Kouri Betki (kouri.betki@rmit.edu.au). This project has received clearance by the Human Resource Ethics Committee (HREC No, BEETAPPS23). Should you have any concerns regarding the conduct of this research project, you are welcome to contact the Executive Officer, RMIT Human Research Ethics Committee, please see details below.

Yours Sincerely,

Jennifer Harlin
Doctor of Philosophy (PhD) degree candidate

Professor Kouri Betki
School of Electrical and Computer Engineering, RMIT University

Any complaints about your participation in this project may be directed to the Executive Officer, RMIT Human Research Ethics Committee, Research & Innovation, RMIT, GPO Box 247E, Melbourne, 3001. Details of the complaints procedure are available at:
http://www.rmit.edu.au/research/hrec_complaints

*2. I have read the plain language statement and agree to participate in this research

☐ Agree
☐ Disagree
### Innovative Problem Solving for Engineers: Measures for Transferability

#### Demographic Information

**3. Are you ...**
- [ ] A student
- [ ] A practicing engineer
- [ ] An academic

If a student:

#### Innovative Problem Solving for Engineers: Measures for Transferability

#### Demographic Information - Student

**4. Current year of study**
- [ ] 1st year
- [ ] 2nd year
- [ ] 3rd year
- [ ] 4th year
- [ ] Master
- [ ] PhD
- [ ] Other
  
  Other (please specify)
  
**5. Have you had any industry experience (either currently or prior to entering university)?**
- [ ] Yes
- [ ] No

#### Innovative Problem Solving for Engineers: Measures for Transferability

#### Demographic Information - Student

**6. If yes, please state the number of year(s) of industry experience you've had.**
If a practising engineer:

<table>
<thead>
<tr>
<th>Innovative Problem Solving for Engineers: Measures for Transferability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographic Information - Practising Engineer</td>
</tr>
<tr>
<td>* 7. How long have you been working in your field (in years)?</td>
</tr>
<tr>
<td>* 8. Highest education completed</td>
</tr>
<tr>
<td>☐ Diploma</td>
</tr>
<tr>
<td>☐ Bachelor Degree</td>
</tr>
<tr>
<td>☐ Masters</td>
</tr>
<tr>
<td>☐ PhD</td>
</tr>
<tr>
<td>☐ Other</td>
</tr>
<tr>
<td>Other (please specify)</td>
</tr>
</tbody>
</table>

If an academic:

<table>
<thead>
<tr>
<th>Innovative Problem Solving for Engineers: Measures for Transferability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographic Information - Academic</td>
</tr>
<tr>
<td>* 9. How long have you been working in the university (in years)?</td>
</tr>
<tr>
<td>* 10. Have you had any industry experience prior to working in the university?</td>
</tr>
<tr>
<td>☐ Yes</td>
</tr>
<tr>
<td>☐ No</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Innovative Problem Solving for Engineers: Measures for Transferability</th>
</tr>
</thead>
<tbody>
<tr>
<td>* 11. If yes, how long did you work in the industry prior to working in the university (in years)?</td>
</tr>
</tbody>
</table>

- 128 -
For all:

### Innovative Problem Solving for Engineers: Measures for Transferability

#### Demographic Information

**12. Your engineering field:**
- [ ] Aerospace
- [ ] Automotive
- [ ] Mechanical
- [ ] Biomedical
- [ ] Chemical
- [ ] Civil
- [ ] Computer and network
- [ ] Electrical
- [ ] Electronic and communication
- [ ] Environmental
- [ ] Industrial
- [ ] Mechatronics
- [ ] Sustainable systems
- [ ] Other
- [ ] Other (please specify)

**13. Your age (in years)**
- [ ] < 20
- [ ] 20-24
- [ ] 25-29
- [ ] 30-34
- [ ] 35-39
- [ ] 40-44
- [ ] 45-49
- [ ] 50 and above

**14. Gender**
- [ ] Male
- [ ] Female
Main section of the questionnaire:

Innovative Problem Solving for Engineers: Measures for Transferability

15. Think back of ONE engineering problem that you had resolved recently. Please allocate how much time you spent on each problem solving stage stated below (in percentages out of a total 100 eg. 30, 50, 20).

Understanding the problem: ____________________
(designing the problem)

Planning the solution: ____________________
(identify the possible solutions, and planning
the implementation)

Implementation of the solution: ____________________

* 16. Did you carry out any evaluation at any stage of your problem solving?

☐ No. Evaluation was not needed since the solution was right.

☐ Yes. The solution was wrong and I had to retrace my steps to find out where I went wrong.

☐ Yes. I always check my assumptions and steps to make sure that my solution is suitable for the problem.
The following are statements related to engineering problem solving and how people develop their long-term problem solving skills. Using the Likert-scale, please indicate to what degree do you agree or disagree with each statement.

* 17. Problems faced by engineers are ill-defined and complex.
   - Strongly disagree
   - Disagree
   - Neither disagree or agree
   - Agree
   - Strongly agree

* 18. The key difference between a good problem solver and an average one lies in his/her ability to understand the problem.
   - Strongly disagree
   - Disagree
   - Neither disagree or agree
   - Agree
   - Strongly agree

* 19. As long as an engineer has the appropriate engineering knowledge, he/she is a good problem solver.
   - Strongly disagree
   - Disagree
   - Neither disagree or agree
   - Agree
   - Strongly agree
20. When facing a problem, people should only ask for help AFTER they have tried to resolve it on their own.

- Strongly disagree
- Disagree
- Neither disagree or agree
- Agree
- Strongly agree

21. It is important to talk to others when solving a problem as everyone can contribute one way or another to a problem resolution.

- Strongly disagree
- Disagree
- Neither disagree or agree
- Agree
- Strongly agree

22. Having discussions with others allows a problem solver to understand different perspectives of the problem that he/she may be facing.

- Strongly disagree
- Disagree
- Neither disagree or agree
- Agree
- Strongly agree

23. It is better to work in groups/teams when solving problems as others can be relied on to come up with the solution.

- Strongly disagree
- Disagree
- Neither disagree or agree
- Agree
- Strongly agree
24. Having formal education results in good problem solving skills.

- Strongly disagree
- Disagree
- Neither disagree nor agree
- Agree
- Strongly agree

25. Good problem solving skills are only developed after having practical experience in the industry.

- Strongly disagree
- Disagree
- Neither disagree nor agree
- Agree
- Strongly agree

26. Good problem solving capability cannot be taught. It must be actively learned.

- Strongly disagree
- Disagree
- Neither disagree nor agree
- Agree
- Strongly agree
27. Expert engineers are better at considering a novel problem with new perspectives compared to novice engineers.

- Strongly disagree
- Disagree
- Neither disagree nor agree
- Agree
- Strongly agree

(novel = new and not resembling something formerly known or used)

28. Expert engineers are able to learn new things better compared to young engineers.

- Strongly disagree
- Disagree
- Neither disagree nor agree
- Agree
- Strongly agree

29. An expert engineer is more likely to come up with creative solutions compared to a younger, inexperienced engineer.

- Strongly disagree
- Disagree
- Neither disagree nor agree
- Agree
- Strongly agree
30. The following are identified as characteristics/traits of good problem solvers. In your opinion how important are these characteristics/traits?

<table>
<thead>
<tr>
<th>Characteristic/Trait</th>
<th>Not important at all</th>
<th>Neither unimportant or important</th>
<th>Somewhat important</th>
<th>Important</th>
<th>Very important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understands the problem</td>
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<tr>
<td>Considers consequences of the solutions</td>
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<td>Has the ability to work with others well</td>
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<tr>
<td>Shares knowledge with others</td>
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<tr>
<td>Open-minded/flexible</td>
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<tr>
<td>Has self-efficacy (self-perception of being capable/self-confidence)</td>
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<tr>
<td>Has systematic methods to solve problems</td>
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<tr>
<td>Creative</td>
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<tr>
<td>Experienced</td>
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<tr>
<td>Has theoretical and/or practical knowledge</td>
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<tr>
<td>Takes action</td>
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<tr>
<td>Comes up with lots of ideas and solutions</td>
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<tr>
<td>Logical</td>
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<tr>
<td>Quick to come up with ideas</td>
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</table>
### Appendix D – Trustworthiness Criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Method/s of establishing trustworthiness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triangulation</td>
<td>The use of two or more methods to collect and analyse data. Data are then compared across different sets to look for similarities and differences.</td>
</tr>
<tr>
<td>Disconfirming evidence</td>
<td>Preliminary themes are identified, and then evidence is sought through the data to confirm or disconfirm the findings. This process focuses on finding data to disconfirm the initial findings. This process particularly assists with the process of being aware if data are being slanted by the researcher’s bias.</td>
</tr>
<tr>
<td>Researcher reflexivity</td>
<td>The researcher needs to disclose personal bias, assumptions and beliefs. Rather than “bracketing” personal bias as suggested by Creswell and Miller (2000), Corbin and Strauss (2008) proposed that it is better that researchers acknowledge and are aware when they are slanting data. Thus memos, developmental diagrams and journal should be used.</td>
</tr>
<tr>
<td>Member checking</td>
<td>Participants are asked to validate data and findings to ensure that the researcher’s interpretation is accurate.</td>
</tr>
<tr>
<td>Prolonged engagement in the field</td>
<td>The researcher needs to spend significant time on the study to ensure that data collection and analysis is not rushed to conclusion.</td>
</tr>
<tr>
<td>*Collaboration</td>
<td>Participants are engaged as co-researchers in the study. The participants are involved in generating the research questions etc.</td>
</tr>
<tr>
<td>The audit trail</td>
<td>The research process is audited by other researchers to ensure that methods and processes are followed accurately. The researcher also keeps a record on the process of data collection and analysis throughout the study.</td>
</tr>
<tr>
<td>*Thick, rich, descriptions</td>
<td>Participants and settings are described in great detail and length.</td>
</tr>
<tr>
<td>Peer debriefing</td>
<td>The results are discussed or evaluated by peers who are familiar with the research or the topic being researched.</td>
</tr>
</tbody>
</table>

Adapted from Creswell and Miller (2000)

* Criteria excluded from this study due to unsuitability for the purpose of the research.