Educating a reflective engineer: learning from engineering experts

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Structured abstract

BACKGROUND
Engineers are expected to engage in the process of reflection for their learning and when resolving problems. This is evident as reflection is one of the focuses in engineering education. Reflection can enhance the learning of students. However, recent literature also found that the process of reflection is not practiced by young engineers. To understand this phenomenon, the authors investigated the perceptions of expert and novice engineers on the process of reflection. This study is part of an overall research into how problem solving performance can be enhanced through formal instructions.

PURPOSE
The purpose of this paper is to investigate the following:

- What can be learned about the process of reflection by comparing responses of expert and novice engineers?
- If there are any differences, what caused these differences?

DESIGN/METHOD
The research design consists of two phases including qualitative and quantitative methods. Initial interview data was collected and analysed using Grounded Theory methodology, involving 22 engineers. The results of the interview data is then verified through a questionnaire, involving responses from 221 engineers.

RESULTS
The study found that novice and expert engineers perceived the process of reflection differently. It was discovered that novice engineers are likely to reflect only when mistakes are made. On the other hand, expert engineers are more likely to reflect continuously when they resolve problems. Moreover, expert engineers usually reflect on both processes and on personal assumptions. Novice engineers are likely to reflect on processes only.

CONCLUSIONS
The outcome of this study has implications for engineering curricula. The insights gained from why expert engineers resolve problems the way they do, highlight the misconceptions that novice engineers have on the process of reflection which need to be addressed. The outcome of the research also revealed what is really required to achieve effective reflection for learning.

KEYWORDS
Reflection, expert, novice, students’ misconception, problem solving

Introduction

The value of reflection for learning and professional development is well-documented in literature (Brockbank, McGill, & Beech, 2002; Feltovich, Prietula, & Ericsson, 2006; Moon, 1999; Schon, 1983). Current literature also suggest that the process of reflection is part of the problem solving process (Belski, 2002; Carlson & Bloom, 2005; Engineers Australia, 2009; Hambur, Rowe, & Luc, 2002; Polya, 1945). Engineers are expected to be able to understand the problem, plan and implement solutions when resolving problems. They should also be able to reflect on and evaluate the solutions (Belski, 2002; Carlson & Bloom, 2005; Polya, 1945). In their investigation on how experts resolved problems, Carlson and Bloom (2005) found that the reflective process is vital to the acquisition of solutions. Experts in their study evaluate initial solutions and adjust their problem solving plan accordingly. Douglas, Koro-Ljungberg, McNeill, Malcolm and Therriault (2012) proposed that students who practiced linear and systematic problem solving processes are considered as reflective problem solvers.

For these reasons, it is appropriate that formal education should incorporate the process of reflection in the curricula. Hazzan and Tomayko (2004) presented a course structure in which reflective practices can be embedded. They suggested a 14-lessons plan that included stages of reflections at the end of each lesson. Palmer (2004) used online journals to instil the reflective practice into students. These journals were completed by the students at the end of each weekly class and formed part of a formal assessment. Though students find the use of the journal useful, it was found that they only accessed the journal weekly as required by the course assessment (Palmer, 2004). Kilgore, Sattler and Turns (2012) used professional portfolios to engage students in reflection on their practice as engineers. The focus of their exercise is to get students thinking about how their prior experiences contribute to their future engineering practice.

While all the abovementioned authors focused on reflective practices that require looking back on tasks and/or events, the authors of this paper took a different approach. Task Evaluation Reflection Instrument for Student Self-Assessment (TERISSA) procedure requires students to evaluate the complexity of a problem, before and after the task is completed (Belski, 2010). Comparisons of the test and exam results of students who used TERISSA and those who did not, showed that those who used TERISSA performed significantly better (Belski, 2010). Despite these efforts in engineering education, there are recent studies that found that younger engineers are not aware of the value of reflection. Adams (2010) observed in his study that students are not carrying out the process of reflection in practice. The authors also noticed a similar observation in young engineers (Harlim & Belski, 2010). Younger engineers rarely linked the concept of reflection as part of the practice of good problem solving, unless prompted.

In order to investigate this phenomenon, the authors interviewed expert and novice engineers and compared their opinions on the process of reflection. Experts are considered to have higher developed ability in reflection compared to novices (Cleary & Zimmerman, 2001; Ertmer & Newby, 1996; Feltovich, et al., 2006; Schon, 1983; Zimmerman, 2002). Therefore, comparisons of the perspectives of experts and novices may give some insights into the gap of understanding that may exist. A more stringent approach to the definition of experts is taken in this study. An “expert” is defined as a person with more than 10 years of experience in his or her field (Chase & Simon, 1973; Prietula & Simon, 1989). This study is part of an overall research into how problem solving performance can be enhanced through formal instructions.

The purpose of this paper is to investigate the following questions:

- What can be learned about the process of reflection by comparing responses of expert and novice engineers?
- If there are any differences, what caused these differences?

Methodology

This study employed mixed methods carried out in two phases (Figure 1). It used both qualitative (Grounded Theory) and quantitative (survey) data collection and analysis. In this study, Grounded Theory was used before the quantitative method. Grounded theory is used to understand the phenomenon of reflection from the perspective of the engineers. Once the findings are established by the interview data analysis, a survey is used to verify some of the previously gathered information. The reliability and replicability of the interview findings are tested by disseminating the survey to a larger sample of engineers.

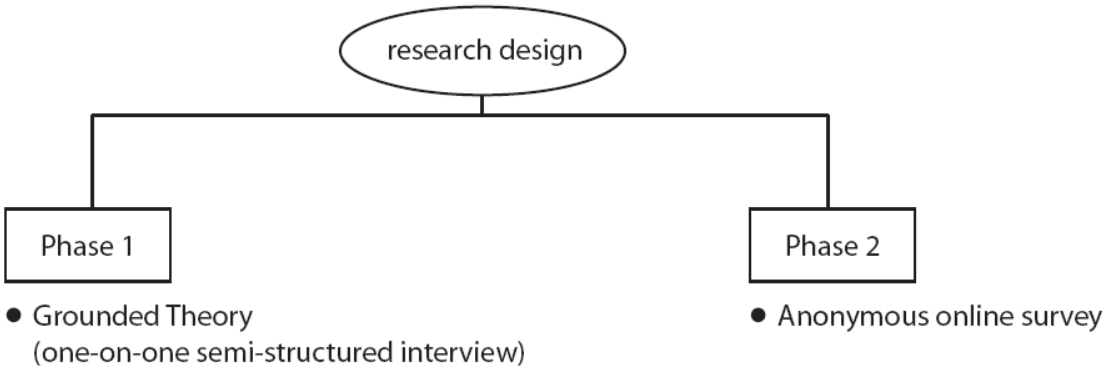


Figure 1: Research design

Phase 1 – Grounded Theory

Initial data was collected using taped semi-structured interviews conducted between 2009 and early 2011. Initial participants were recruited from a problem solving elective in RMIT University and also from various engineering organisations. The interviews were carried out in cycles using theoretical sampling (Figure 2). In this research, after each cycle, the interviews were transcribed and analysed. Interview questions were then adjusted to ensure that better data acquisition can be achieved in the next cycle.

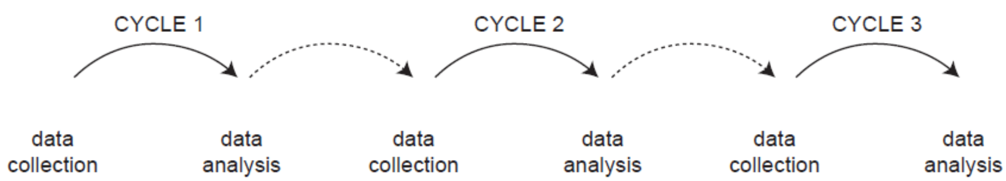


Figure 2: Data collection and data analysis process

Table 1 Participants demographic

No. of participants	No. of work experience in full-time engineering field.	Classification
6	0 years (Students and recent graduate with no work experience in the engineering field.)	Novice Class 1 (N1)
6	1-5 years	Novice Class 2 (N2)
3	6-10 years	Mid-level (M)
7	>10 years	Experts (E)

Data saturation was used as a guide to determine how many participants should be involved in the first phase of the research. The first cycle included 7 participants, the second 6 participants and the third cycle involved 9 participants. Data saturation was observed when carrying out the third cycle, resulting in a total of 22 engineers interviewed, ranging from novice to experts (students to professionals with more than 10 years working experience), including 15 male and 7 female engineers. Refer to Table 1 for the participants' demographic breakdown.

To get better depth of understanding of the data and to ensure rigorousness, analyses in this phase of the study are carried out in various ways and a number of times. For example, in addition to carrying out analysis after each cycle, an overall analysis was also conducted after the final cycle was completed. Initially, the transcripts were micro-analysed with the help of NVivo software to identify common themes. The authors also listened to all the recording again to get an overall understanding. Once emerging themes have been identified, relevant quotes were extracted from the transcripts. The use of memos, diagrams and reflection journal were integral to the analyses (Corbin & Strauss, 2008). Verification was carried out by discussing the findings with participants. All these processes are consistent with the practice of ensuring rigour and validity in a qualitative approach.

Phase 2 – Anonymous online survey

The last phase of data collection used the survey method. The aims of this phase were to enable the researchers to generalise the findings derived from the interview data and to confirm or invalidate the observations made from the interview data. The questions used in the survey were generated from quotes and ideas from the Phase 1 data collection. A stringent approach to questionnaire development was used in this study to ensure that the questions asked are appropriate for data collection (Figure 3). The questions were tested a number of times prior to full launch. The survey phase data collection was carried out between 29 March 2012 and 16 June 2012.

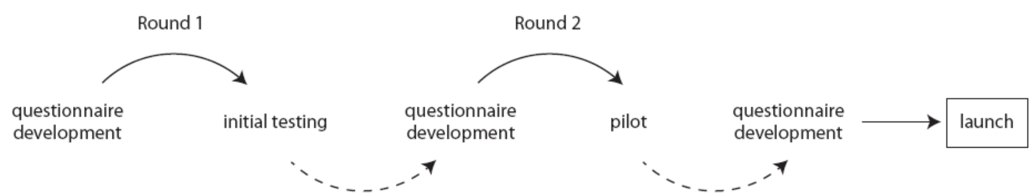


Figure 3: Survey development process

To investigate the reflective process, the responses to the following question were considered: **Did you carry out any evaluation at any stage of your problem solving?** The following answers are available: (1) *No. Evaluation was not needed since the solution was right*; (2) *Yes. The solution was wrong and I had to retrace my steps to find out where I went wrong*; and (3) *Yes. I always check my assumptions and steps to make sure that my solution is suitable for the problem*. Comprehensive demographic questions were also collected. The survey responders were required to state their industry experience. This was important in order to establish the novices and experts within the responders' pool.

The link to the online survey was sent to the engineers who had participated in the interview phase of the research. The link was also sent to various engineering organisations and different engineering schools. To increase randomness and representativeness of non-probability sampling, the link was also advertised on the social media sites Facebook, Twitter and LinkedIn. A total of 273 engineers started the survey. However, the participants stopped completing the survey at different stages of the questionnaire. Out of 273 who started the survey, 221 answered the question pertaining to the evaluation and reflection. This included 48 female and 173 male engineers.

Results

When the interview responses from the experts and novices were compared, differences in their opinions on the process of reflection were found. These differences are summarised in Table 2. Experts in the study believed that reflection is an integral part of problem solving and should be undertaken all the time. In contrast, the novices believed that reflection is only necessary when mistakes are made. In addition when asked about how they would undertake the process of reflection, novices spoke about evaluating processes to rectify an error. On the other hand, experts believed that both assumptions as well as procedures need to be reflected upon.

Table 2: Summary of differences of opinions on the theme of reflection between expert and novice engineers in the study

Expert	Novice
<u>Always reflect.</u> *Eg. 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)*	**<u>Reflect if initial solution was wrong.</u>** *eg. [Reflection] only good when you are stuck on something….**I usually only reflect when I am stuck in something**. (N2-1)*
<u>Evaluate both procedure and personal assumptions.</u> *Eg. You have to ask yourself the question what happens if I'm wrong in my **assumptions**. How will that affect my solutions? … You've got to **test your solution out and evolve it**. (E3)*	**<u>Evaluate steps or procedure to see where they went wrong.</u>** *eg. I would actually go back to step one. Check what you've **done**…step by step and start troubleshooting. (N2-2)*

To test the interview findings with larger samples of engineers, the following question was considered: **Did you carry out any evaluation at any stage of your problem solving?** The following answers are available: (1) *No. Evaluation was not needed since the solution was right*; (2) *Yes. The solution was wrong and I had to retrace my steps to find out where I went wrong;* and (3) *Yes. I always check my assumptions and steps to make sure that my solution is suitable for the problem*. Those that answered (1) or (2) were combined to form one single response that suggests that evaluation is only carried out when the final solution is unsuitable for the problem. To investigate if there are differences in the way specific groups respond to this question, the information was sorted according to the engineers' industry experience (Figure 4).

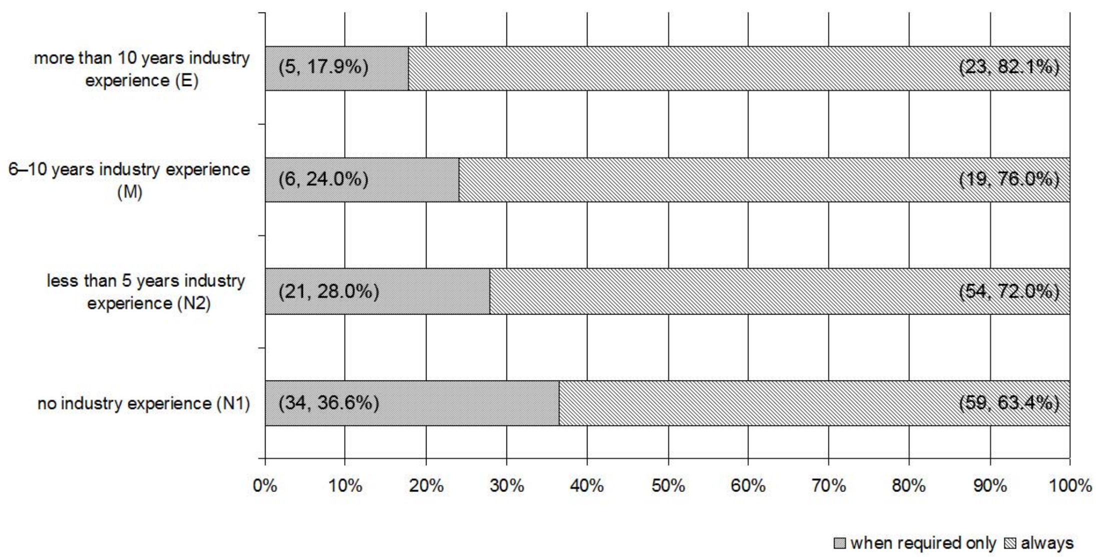


Figure 4: Survey responses of engineers and the evaluation process broken down into groups based on industry experience

Out 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, 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 gained, the more likely they are to be aware of the need for reflection. The impact of the industry experience on the awareness of the need for reflection is also supported by the interview data as exemplified by a comment from a senior engineer (E6):

> *"[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."*

Discussion

In investigating the differences between the responses of novice and expert engineers on the concept of reflection, distinct divergences in their perception of this process were found. These differences have allowed the identification of areas of novices' misconceptions on the process of reflection. By understanding the experts' perspective, two specific areas that need to be addressed were identified: i) when to reflect and ii) what to reflect on.

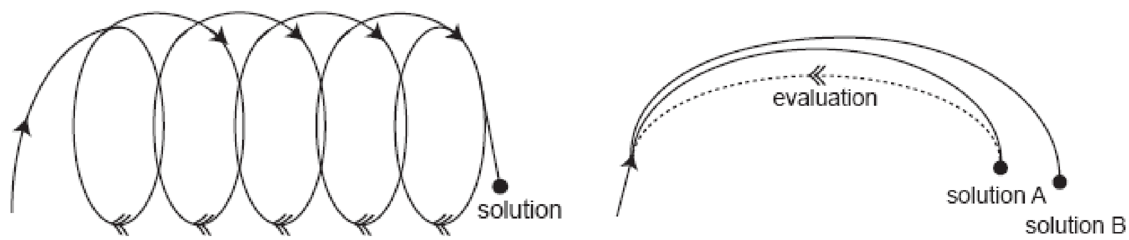
Expert engineers in this study stressed that the process of reflection is necessary all the time. The interview data confirms that the use of reflection is synonymous with the practice of being an expert as covered by existing literature (Ertmer & Newby, 1996; Feltovich, et al., 2006; Schon, 1983; Zimmerman, 2002). In contrast, novice engineers perceive the process of reflection is a necessity only when mistakes are made. In his research, Palmer (2004) reported that students were only accessing the journal as required by the assessment criteria. These suggest that unless there is a need, novices are unlikely to carry out the process of reflection. This provides a reason as to why in current literatures (Adams, 2010; Harlim & Belski, 2010), reflection is not priority of novice engineers when resolving problems.

The authors believe that this perception could be the result of the widely espoused view that problem solving is a complete four steps comprising of understanding the problem, planning, implementing and evaluation as suggested by literature (Belski, 2002; Carlson & Bloom, 2005; Polya, 1945). Therefore, novice engineers tend to believe that the problem solving process is a linear process of understanding the problem, planning and implementation, followed by evaluation if necessary. The concept of linear problem solving practise by students were also apparent in the study of Douglas et. al. (2012).

What was interesting was the way experts utilise the process of reflection. Expert engineers in the study believed that both procedures and assumptions need to be evaluated and reflected upon. On the other hand, the younger engineers in Phase 1 of the study indicated that they would evaluate their procedures. Cleary and Zimmerman (2001) indicated that experts have a higher ability to reflect. However, experts in their study carried out task-based reflections which were made to correct errors in performances. Their experts behaved similar to the novices in this research. The differences in the results can be attributed to the stringent approach to the classification of expertise. Experts who has more than 10 years industry experience, focuses on not just correcting procedures but questioning the way they perceive things.

The evaluation of personal assumptions is crucial for experts' performance in when resolving problems. As expertise is gained, increased bias may occur as experts may operate solely in their field of expertise (Belski & Belski, 2008; Feltovich, et al., 2006; Harlim & Belski, 2011). In resolving problems, an expert may need to diagnose a problem beyond his or her expertise. Feltovich, et. al. (2006) suggested that the use of reflection is as a mechanism for experts to check their knowledge and understanding. This allows them to function even outside their own field of expertise.

It is proposed that when an expert 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 during problem solving, when experts go through each cycle, they are improving their understanding of the problem. This enables 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. The idea that experts do not utilise linear plans is supported by Cross (2004) who cited examples of studies where experts were found to deviate from linear processes when resolving ill-defined problems. Therefore, while Douglas et. al. (2012) propose that systematic linear processes assist students in resolving complex problems, the findings in this paper suggest that students should be taught systematic methodologies that allows them to accommodate the cyclic nature of complex problem solving. The differences of the concepts of reflection from the two differing perspectives are summarised in Figure 5.



(a) Expert: evaluation and reflection for holistic problem solving

(b) Novice: evaluation and reflection driven by solutions

Figure 5: Evaluation and reflection cycle in the perspective expert versus novice engineers.

The data also accounts for these differences in perspectives. It is suggested that industry experience contributes to the understanding that problem solving is a cyclic process. Reflectiveness is an acquired practice resulting from this understanding. Therefore, it can be proposed that exposure to real engineering problems conveys the realisation of the need to reflect. Although no statistical significance was found in the data presented in Figure 3, the trend in the survey data supports this argument. When engineers were surveyed about their problem evaluation habit, it was observed that the more years in the industry engineers had, the more likely they were to report that they continuously engage in reflection while problem solving.

Through understanding the process of reflection from the perspective of expert engineers, the authors believe it is imperative that younger engineers should be trained in developing the habit of reflecting. They should also be trained in proper evaluation processes that not only consider procedures, but also personal assumptions. The prevalence of the reflective practices in education that require students to evaluate a past task or event (Hazzan & Tomayko, 2004; Kilgore, et al., 2012; Palmer, 2004) can contribute further to the misconception that reflection is an after-thought procedure that is to be carried out at the end of a task or event. Perhaps other types of reflection activities need to be considered to address misconceptions on the reflection process.

Conclusion

The findings presented in this paper have provided some insights as to why the process of reflection is not a priority in the opinions of novice engineers. The differences between the responses of novice and expert engineers revealed areas of misconceptions that young engineers have on the process of reflection. By understanding the process of reflection from the perspectives of expert engineers, it provided insights into when and what type of reflection should be carried out. The findings in this paper have implications to the engineering curricula. To ensure that effective strategies of reflection is taught to and taken on board by students, misconceptions held by novice engineers need to be addressed. If these misconceptions persist, any effort to instil the practice of reflection in novice engineers may be counter-productive.

The interview data has provided insights on how experts and novices utilise reflection when resolving problems. Although the findings have been compared against additional survey data, other options of triangulating the interview findings are still being considered. In this paper the links between expertise and propensity for reflection is investigated. There is a further need to explore other factors such as age, gender and field of study/expertise that may impact reflectiveness. While the authors have advocated that students need to be taught the right tools to instil the habit of reflection, further research should focus on investigating what some of these tools are. Findings presented in this paper also raise the question if sufficient effort is made in conveying real/industry engineering work practices in universities. This can be a future research direction.

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