Young engineers and good problem solving: The impact of learning problem solving explicitly

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***Abstract**: This paper explores what young engineers perceive as good problem solving and how these factors are impacted when students learned problem solving explicitly. Data from three sources were considered: surveys, interviews and Repertory Grid Technique data. It was found that teaching problem solving explicitly impacts perceived ability to solve problems which the participants believe to be important for motivation in facing problems. It was also found learning problem solving explicitly impacts the ability to consider problems from different angles, creativity and management of information which participants consider essential for good problem solving.*

Introduction & Literature Review

Education of engineers is focused on developing the engineers' ability to solve problems (Beder, 1999; Roth, 2007). A problem is defined as an unusual situation that one faces where the solution may not be immediately visible (Tallman & Gray, 1990; Yeap, 1998; Carlson & Bloom, 2005). Hambur, Rowe, and Luc (2002) propose that good problem solving involves the ability 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 strategies, apply and evaluate strategies. Engineers Australia (2009) has defined engineering problem solving as the ability to identify the technical nature of the problem, achieve a solution and evaluate the impact of the solution to the system. Creativity, the ability to cope with ambiguity and see links in engineering to other disciplines are also considered as aspects of good problem solving by Engineers Australia (2009).

Mayer (1998) posits that problem solving requires domain specific knowledge, the skills to use that knowledge and motivation. While he suggested some methods to develop these areas, it was not engineering specific. The methods that he suggested were also not backed up by existing empirical data. Brodie and Brodie (2009) acknowledge that engineering is a 'predominantly a knowledge-based industry' (p. 137) where information is a commodity. They recognise the need on teaching students skills to interpret, use and renew information (Brodie & Brodie, 2009). How can such skills be taught to engineers effectively? What can engineering educators do to ensure that the future engineer can solve a variety of problems?

It is proposed that problem solving skills can be taught in two ways; infusion and enrichment (Prawat, 1991; Belski, 2009). Some examples of infusion method are the use of problem-based learning and authentic learning (Benjamin & Keenan, 2006; Lindsay, Munt, Rogers, Scott & Sullivan, 2008; Brodie, Zhou & Gibbons, 2008). One specific course that uses the enrichment method is an RMIT-wide elective which taught students tools of Theory of Inventive Problem Solving (TRIZ) (Belski, 2009). Belski and Belski (2008) suggest that problem solving tools should assist novices to understand the problem and manage information, while for experts it should remove biases. Belski (2009) found that students' opinions about the improvement of their problem solving ability were significantly higher when they were taught TRIZ. Though the data has shown improvement, Belski (2009) has not explored what aspects of the tool had led to this perceived improvement.

While there is much emphasis on problem solving in engineering, what does problem solving mean to young engineers? Do their understanding of good problem solving fit within current definitions? Does learning problem solving explicitly impact what these engineers believe as aspects of good problem solving skills?

Thus the following research questions are posed:
1. What are characteristics of a good problem solver in the opinions of young engineers?
2. What is the impact of explicitly teaching problem solving to students in relation to what young engineers think is good problem solving?

Methodology

This research considered data from three sources; students' surveys, interviews and Repertory Grid Technique (RGT) data (Fransella, Bell & Bannister, 1977).

The students' survey included responses from 20 students who were enrolled in an RMIT-wide elective which taught students tools of Theory of Inventive Problem Solving (TRIZ), in Semester 2 of 2009. The students were asked to fill in a questionnaire with 6 questions using 5 Likert-scale, both at the commencement and the conclusion of the course. To investigate the impact of this course on students' perceived ability to solve problems, we were interested in the following questions; Question 1 - *I am very good at problem solving*, Question 3 - *I am never intimidated by the unknown problems*, Question 4 - *I am unable at tackling unfamiliar tasks*, Question 5 - *So far I have been able to resolve every problem I faced*, and Question 6 - *I am certain that I am able to resolve any problem I will face*. Question 2 (*Problem-solving tools are of vital importance*) was not considered in the analysis as it is not relevant to the research questions. In the analysis, responses to question 4 were inverted to allow for standardised analysis in which changes in positive numbers indicate improvements.

The questionnaire also included 3 open-ended questions. This research is particularly interested in their responses to the question '*Do you expect that the way you think may change as a result of this course? How do you think it might change?*' which was asked in the pre-course questionnaire. We believe that the responses to this question give an indication to what students perceive as aspects of good problem solving. The responses to the question '*Do you think that your thinking changed as a result of this course? How did it change?'* which was asked in the post-course questionnaire were analysed to investigate the impact of the course.

To investigate what participants consider as characteristics of good problem solvers, in-depth interviews were carried out. Four out of 20 students responded and participated in the interviews. Their responses were compared against 2 recent graduates and 2 young engineers who are working in the field and have not taken the TRIZ course. The responses from the interviews were also used to investigate if learning problem solving explicitly had any impact on problem solving ability. Participants who are graduates and professionals were invited to participate via their institutions or snowball sampling. The responses were analysed thematically with the aid of the NVivo software.

To probe further what participants consider as good problem solving, they were asked to carry out the RGT component straight after the semi-structured interviews. The RGT was chosen as it is believed that the use of this technique would enable us to capture the underlying meanings that participants may have in relation to what they believe is good problem solving. In addition, the RGT was used to verify the data gathered during the verbal interview. The RGT was conducted using the software, Idiogrid. The qualities that participants believed to be linked to good problem solving were analysed using content analyses and grouped into themes.

Results

One of the general themes that emerged from the interviews and the RGT sessions was that participants considered good problem solvers are people who are willing to face problems. The participants believed that confidence in personal ability to tackle uncertainties is important in motivating someone to face problems. This was verified when some of the students surveyed commented in the pre-course questionnaire:

> *'The course may change my view of looking at a problem when it presents itself the first time.'*
> *'I expect the way I approach problems to change with respect to how I view it and how I size it up.'*

The differences between the pre- and post-evaluation of students' perceived problem solving ability were analysed and the results are shown in Figure 1. For all questions apart from question 4, at least 75% of the observations lie within the positive region, indicating a trend towards improvement. Most of the spread of the responses lie between ranges of -1.00 to 2.00. However, a few less common responses which showed a higher improvement or negative improvement were also observed (question 4, question 5 & question 6). Due to the violation of the assumption of normality for each question, nonparametric methods were used for statistical inference. According to the Wilcoxon Signed-ranks Test, questions 1 ($p=0.026$), 3 ($p=0.017$), 5 ($p=0.005$) and 6 ($p=0.013$) showed a statistically significant change towards improvement. Changes in responses to question 4 were not statistically significant ($p=0.285$).

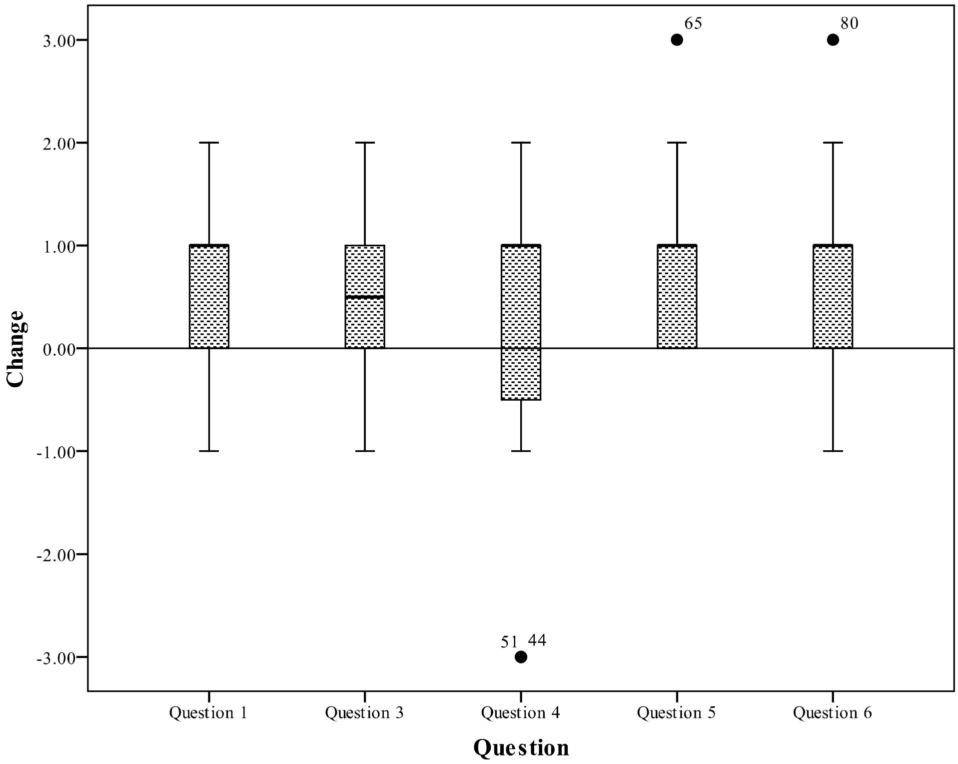

Figure 1: Box plot of differences in responses to question 1, 3-6.

Further interviews confirmed that learning problem solving tools explicitly certainly impacts the motivation to face problems as seen when the responses between a participant who took the course and a participant who did not take the course were compared.

Table 1: Comparison between participants – Motivation and self-belief of being capable

Participant who took the course	Participant who did not take the course
'I've always had the attitude I'm not going to be able to do this like what am I going to do here? But ***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****.'*	*'I can say the problem was during one of my course, my undergraduate course…it was related to programming. 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****. And the program kept getting error message. It* ***was really frustrating and sometimes you just want to give up****.'*

The ability to view a problem from a variety of angles was also raised during the interviews and the RGT data analysis. Participants believed that good problem solvers have the capability to identify and analyse problems from different angles. Students who were surveyed also made the link between good problem solving and having the ability to consider problems holistically as seen in the comments in the pre-course survey:

> *'Having the skills to be able to look at things from another angle for a more efficient way to do things.'*
> *'Thinking about the problems in all angles.'*

So how does the use of a problem solving tool like TRIZ facilitate consideration of a problem as a whole system? The impact is noticed when comparing responses between a participant who did the course and a participant who did not take the course.

Table 2: Comparison between participants – Viewing a problem as a whole

Participant who took the course	Participant who did not take the course
'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****.'*	*'The 2nd problem actually* ***was not analysed properly because it was out of the scope of the project****… I think what actually happened* ***was the new one [problem] that we discovered has always been there. But no one realised that it was there****. But then everyone knows that every project that you do sometimes, or most of the times never 100% will complete straightaway. Or basically plan A never works, you always need a plan B.'*

The statement from the participant who did not take the course (shown above), indicates that not having a tool to predict the entirety of the problem may lead to delays in resolving problems due to misdiagnoses. The reliance on contingency planning becomes essential. In contrast, a student who was interviewed commented:

> *'…build[ing] 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 forecoming 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.****'*

Speaking about the lack of being taught problem solving explicitly, one of the young professionals mentioned:

> *'It is unfortunate no one teaches it in the education system.* ***So it is about finding it out yourself****. I supposed it'll be easier if someone teach you that so you don't have to go* ***through the hard way of trying to find it yourself because that journey is not as easy.*** *'*

Statements such as this indicate that the participant felt those who had not taken the course have to rely on creating their own problem solving methodologies through trial and error. In such cases, experience becomes important. One of the recent graduates said:

> *'It's from experience.* ***If we face more problems and we come up with lots of solutions, it will help us with that skill.****'*

The idea of taking the time to analyse, and understand the problem before looking for a solution was also raised during the interviews and RGT sessions as a process that good problem solvers engage in. The participants linked this theme with management of information. In the post-evaluation questionnaire one of the students commented:

> *'Next time I face a problem I will try to identify what is it really about and the target task before suggesting my solution.'*

One of the young professionals believed that problem solving requires time so one can consider all aspects of the information that is required to solve the problem. The participant stressed that problem solving:

> *'… 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*** *and then it* ***helps you to come up with an outcome.'***

Some of the students who had learned TRIZ believed that it had equipped them with a tool that helps them to gather information, to structure it and to interpret it as seen in the comments below:

> *'…transformation of data and present it to make it flexible out/end result.'*
> *'I've learned that we don't always use all the knowledge that we have.* ***In the course it showed me how to use this method to make sure that I use all the knowledge that I've learned in the past and apply it to the problem.*** *Instead of just looking at it straight forward so just makes it a lot easier to find like a solution to something.'*

Participants also considered creativity as part of good problem solving which is facilitated by open-mindedness. It was found that TRIZ helped to remove personal biases, encouraging students to explore creative solutions. Participants who did not take the course tend to rely on traditional approaches to solve unknown problems.

Table 3: Comparison between participants – Creativity

Students' survey responses	Participant who did not take the course
'… instead of ruling out possibilities as I may think they are impossible, I now can confidently take a good look and develop a solution to a problem.' *'… to some degree removed my bias from problem solving'.*	*'[when we] don't know what is the right or wrong answer… [we would] go with the flow…probably* ***being conservative*** *is good too.* ***Choose something traditional that people have used before'***

Discussion & Conclusion

When it comes to facing unknown problems, it was found that participants considered motivation as an important factor. The importance of motivation in problem solving supports Mayer (1998) but this research further discovered that the self belief in the capability to handle unknown problems impacts motivation. It was found that students who took the course had an improvement in their perceived ability to solve unfamiliar problems which is similar to the findings of Belski (2009). While all the 4 other questions were statistically significant, question 4 was not. The students who answered this question may have been confused by the double negative in the question.

Participants also believed that good problem solving requires consideration of a holistic view of problems. Participants also perceived that good problem solvers are creative because they are not bounded by their biases. These characteristics are aligned with Engineering Australia's (2009) definition of problem solving. The participants who took the course felt that they were equipped with a tool to view a problem as a whole system, and consider solutions that are outside the box which support Belski and Belski (2008). Participants who did not do the course rely on contingency planning and when facing uncertainties, rely on traditional approaches.

Participants valued taking time to consider problems which they linked to the ability to collect, analyse and interpret information which is aligned with Hambur et. al. (2002), and Brodie and Brodie (2009). Participants who took the course believed TRIZ helped them to organise information. Participants who did not take the course discussed situations where they had missed information. The participants who did not learn TRIZ believed that they need to develop their own methodologies to solve problems through time and experience. While the understanding of problem solving by the young engineers involved is aligned with current literatures, some gaps were also found. Engineers Australia (2009) and Hambur et. al. (2002) discuss the importance of post-evaluation after the problem has been resolved. Yet, the participants in this research did not raise this point at all. Perhaps the young engineers interviewed did not see reflection as a very important aspect of problem solving skills.

This research has limitations. The number of research participants is small. As interview participation was voluntary, only 4 out of 20 enrolled students were willing to take part in the in-depth interviews, making a total of 8 participants who were involved in the interview stage. The students were enrolled in an elective thus they may be self-selecting and are more likely to be interested in the problem solving field to begin with. In addition, the interview group mainly consisted of male participants, which may result in a gender-biased study. Further research data need to be collected from a wider range of participants to evaluate what engineers consider as characteristics of good problem solvers. A set of measures will then be developed and can be applied to investigate if true "improvement" of problem solving ability is achieved through the TRIZ course.

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