Do we succeed in developing problem-solving skills – the engineering students' perspective

Tom Steiner
RMIT University, Melbourne, Australia
tom.steiner@rmit.edu.au

Iouri Belski
RMIT University, Melbourne, Australia
iouri.belski@rmit.edu.au

Jennifer Harlim
RMIT University, Melbourne, Australia
jennifer.harlim@rmit.edu.au

James Baglin
RMIT University, Melbourne, Australia
james.baglin@rmit.edu.au

Roy Ferguson
RMIT University, Melbourne, Australia
roy.ferguson@rmit.edu.au

Tom Molyneaux
RMIT University, Melbourne, Australia
tom.molyneaux@rmit.edu.au

Abstract: *This paper examines findings of a problem-solving skills survey conducted at RMIT in 2010-2011, involving 320 student respondents. It will discuss the following questions: (1) Are there any differences in perceptions of students from different schools on their problem-solving skills? (2) Do students perceive themselves as better problem solvers as a result of their engineering degree studies? (3) What activities improved students' problem-solving skills the most? The findings suggest an approach to enhance student-perceived effectiveness of their problem-solving skills.*

Introduction

The explicit need for graduates with well developed problem-solving skills has emerged strongly in many professions. The Australian Chamber of Commerce and Industry and the Business Council of Australia pronounced problem-solving as one of the eight Employability skills for the future (DEST, 2002). Australian graduate recruiters listed problem-solving skills as one of the nine Generic Employability Skills they expect a graduate to possess in addition to appropriate academic results (Graduate Careers Australia, 2007). Problem-solving skills have been included into sets of graduate attributes, such as those, defined by the Australian Technology Network (Australian Technology Network, 2000). The area was identified as exceptionally important for engineering graduates in the influential work of the US National Academy of Engineering on the qualities required of engineers for the 21st Century (National Academy of Engineering, 2005). Australian engineering accrediting body has confirmed the competency "to undertake problem identification, formulation, and solution" as one of the six key engineering abilities has defined problem-solving in the following way (Engineers Australia, 2009): (a) Ability to identify the nature of a technical problem, make appropriate simplifying assumptions, achieve a solution, and quantify the significance of the assumptions to the reliability of the solution; (b) Ability to investigate a situation or the behaviour of a system and ascertain relevant causes and effects; (c) Ability to address issues and problems that have no obvious solution and require originality in analysis; (d) Ability to identify the contribution that engineering might make to situations requiring multidisciplinary inputs and to recognise the engineering contribution as one element in the total approach.

As identified by many researchers, efficiency and creativity in problem-solving in semantically rich domains is underpinned by three main components: (i) sound discipline-relevant skills, (ii) appropriate skills in creativity and (iii) a high level of motivation towards the task (Amabile, 1983; Bandura, 1977; Harlim & Belski, 2010; Simon, 1996). Therefore, the challenges faced by engineering academics spread far beyond the need of guiding their students in gaining extensive scientific, engineering and professional knowledge. Engineering educators are also expected to find effective ways of equipping their students with numerous creativity heuristics as well as high problem-solving self-efficacy skills.

This study intended to investigate perceptions of engineering students at RMIT on their problem-solving skills over four years of study and to shed light on the following questions:

- Is there any difference in perception of students from different Engineering Schools on their problem-solving abilities?
- To what extent do students perceive themselves as better problem solvers as a result of studying in an engineering program?
- What activities do engineering students believe most improve their problem-solving skills?

Methodology

All the data presented in this paper comes from a survey which was conducted to gain an understanding of the self-perceived ability and attitudes of students related to problem-solving in a cross-section of undergraduate engineering students from three RMIT engineering schools. The survey was administered twice. The first survey was conducted at the end of semester 2, 2010 and it involved students from Year 1 through to Year 4, labelled "Y1-Y4" (after having studied one year through to four years in an RMIT engineering program). The second survey was conducted early in semester 1, 2011 with only new first year students; these students were labelled as "Year 0", having completed zero years in an RMIT engineering program.

Participating students were enrolled onshore in Melbourne in the School of Civil and Chemical Engineering (SCECE), the School of Electrical and Computer Engineering (SECE), or the School of Aerospace, Mechanical and Manufacturing Engineering (SAMME). The sample set of 320 participating students across all Schools comprised the following characteristics: 83% male/17% female; 81% domestic/19% international; 98% full-time/2% part-time. The students participating in the survey represented about 8% of the total population of engineering undergraduates across the three Schools. The distribution by years at RMIT of all students in the sample set was Year 0 – 24%; Year 1 – 14%; Year 2 – 15%, Year 3 – 17%, Year 4 – 30%. The distribution of participants by School was SCECE – 78 students, SECE – 112 students, SAMME – 130 students.

The survey comprised a quantitative section, and a qualitative section. In the quantitative section all student participants, irrespective of experience level, responded to the same six strong statements. These statements were developed to judge students perceptions of their problem-solving abilities and their attitude towards problem-solving skills (Belski, 2009; Belski, Baglin, & Harlim, 2011). Students were asked to indicate their responses to the six statements on a 5-point Likert scale ranging from (1) strongly disagree to (5) strongly agree. These statements were: (Q1) I am very good at problem-solving; (Q2) Problem-solving skills are of vital importance; (Q3) I am never intimidated by unknown problems; (Q4) I am unable to tackle unfamiliar problems; (Q5) So far, I have resolved every problem I faced; (Q6) I am certain that I am able to resolve any problem I will face.

In the qualitative section students finishing their studies in Year 1 to Year 4 (cohort Y1-Y4), or just starting their studies in their first year (cohort Y0), were asked to provide open-ended responses to the following questions: (Q7) Do you agree that your thinking has changed as a result of your study at RMIT? Please explain why you selected Yes or No. (for students in cohort Y1-Y4), or Do you expect that your thinking will change as a result of your study at RMIT? Please explain why you selected Yes or No. (for students in cohort Y0); (Q8) What methods and approaches used by your RMIT teachers improved your engineering problem-solving skills the most? (for students in cohort Y1-Y4), or What methods and approaches used by your teachers so far improved your engineering problem-solving skills the most? (for students in cohort Y0); (Q9) Think of someone you believe to be a good problem solver. Why do you think he/she is a good problem solver? (Q10) How do you think you develop your problem-solving skills?

Results

Is there any distinction between perceptions of students from different Engineering Schools on their problem-solving abilities?

Kruskall-Wallis tests, which are a non-parametric equivalent to the one-way analysis of variance (ANOVA), were performed to determine if there were statistically significant differences in response patterns to the quantitative problem-solving statements (Q1-Q6) across the three schools. Non-parametric methods were used because Likert scales were unlikely to satisfy the assumptions of the parametric ANOVA (i.e. normality and homogeneity of variance). Statistically significant tests were followed-up with multiple pairwise comparisons using Wilcoxon rank-sum tests to identify which specific schools different significantly on response patterns. Wilcoxon rank-sum tests are a non-parametric alternative to the two-sample *t*-test. The multiple comparisons were compared to an adjusted Bonferroni significance level to account for the inflated Type I error caused for testing multiple statistical hypotheses. The Bonferroni correction divides the significance level by the number of comparisons to be made. Therefore, as three comparisons were made (SCECE vs. SECE, SCECE vs. SAMME, and SECE vs. SAMME), the adjusted significance level was 0.05/3 = 0.0167.

Table 1 shows the *p*-value of the Kruskall-Wallis tests. One statistically significant difference was found for Statement 3, $p = .016$. Subsequent Wilcoxon rank-sum tests for pairwise comparisons found that SAMME had a statistically significantly higher perceived level of agreement for Statement 3 compared to SCECE, $p = .005$.

Table 1. Comparison of Problem-solving Statements Across Schools

		School			K-W
		SCECE	SECE	SAMME	*p**
	N	112	81	132	
1. I am very good at problem-solving	M	3.86	3.93	4.05	.190
	SD	0.77	0.72	0.67	
2. Problem-solving skills are of vital importance	M	4.60	4.57	4.68	.423
	SD	0.79	0.74	0.63	
3. I am never intimidated by unknown problems	M	2.88	3.22	3.28	.016
	SD	1.08	1.13	1.09	
4. I am unable to tackle unfamiliar problems	M	2.57	2.38	2.57	.550
	SD	1.12	0.97	1.15	
5. So far, I have resolved every problem I faced	M	2.87	3.15	2.99	.204
	SD	1.10	1.15	1.12	
6. I am certain that I am able to resolve any problem I will face	M	3.29	3.53	3.44	.220
	SD	1.03	0.99	0.99	

To what extent do students perceive themselves as better problem solvers as a result of studying an RMIT engineering degree?

In order to gain insight into the influence of time in their degree program on students' self-perceptions of their problem-solving skills and attitudes the variation in responses across year levels was examined for each of Q1-Q6 in the three schools. The mean value variations of these responses for each School, and the averages of all Schools are plotted below in Figure 1 through to Figure 6.

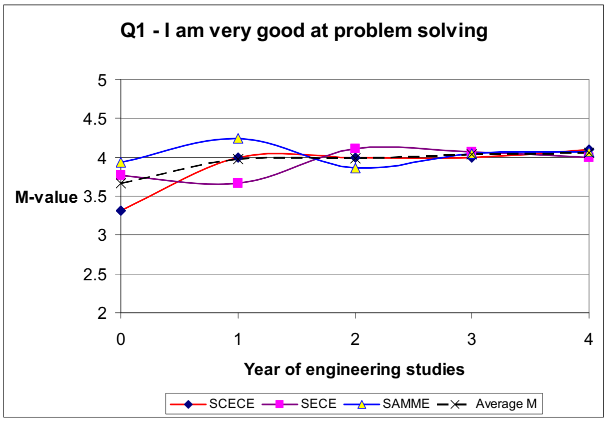

Figure 1: Response to Q1 by year and School

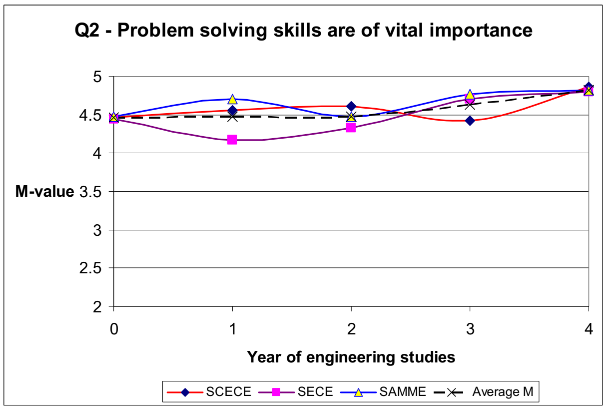

Figure 2: Response to Q2 by year and School

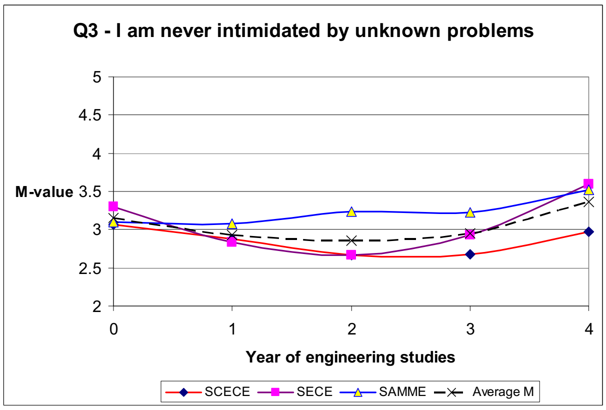

Figure 3: Response to Q3 by year and School

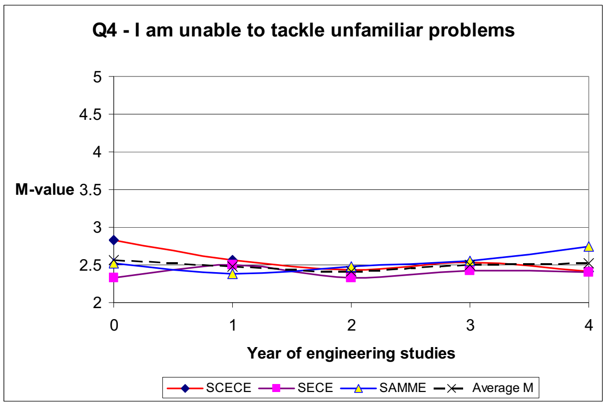

Figure 4: Response to Q4 by year and School

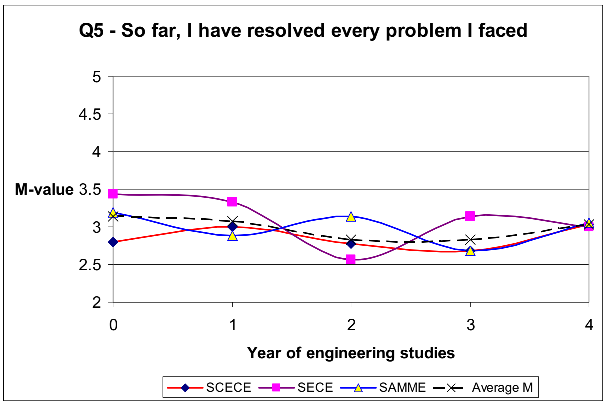

Figure 5: Response to Q5 by year and School

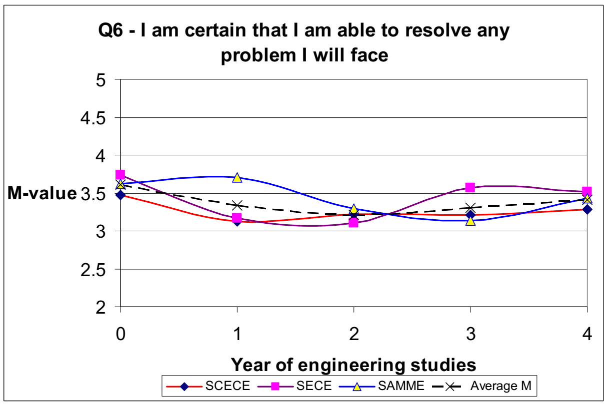

Figure 6: Response to Q6 by year and School

The average of all responses for Q1 (I am very good at problem-solving) shows a significant improvement (K-W χ^2 [$df = 4$] = 16.728, $p = 0.002$) in student self-perception of skill in this area during their first year, followed by only very gradual non-significant improvements during the remaining three years. Multiple comparisons using Wilcoxon rank-sum tests found statistically significant differences between Year 0 and 4, $p < .001$, Year 0 and 3, $p = .006$, Year 0 and 1, $p = .001$.

The changes in students' perception on the importance of problem-solving skills (Q2) were also statistically significant (K-W χ^2 [$df = 4$] = 17.283, $p = 0.002$). Multiple comparisons using Wilcoxon rank-sum tests found a statistically significant differences between Year 2 and 4, $p = .006$ and Year 0 and 4, $p < .001$. This means that over four years students have sharpened their belief in the importance of problem-solving in engineering. It is interesting that accompanying this significant change in perception, students' responses to Q5 and Q6 suggest reduction in the belief that they will be able to consistently resolve problems they face. This is consistent with a perception by students that they may lack knowledge of broad problem-solving methodologies as opposed to having, through particular studies in their programs, developed "tool-kits" of processes for solving a range of specific problems.

The data shown in figure 3 suggests that during the first two years of their engineering studies students experience a growing sense of intimidation in the face of unknown problems as the difficulty of problems to be solved increases. This appears to be ameliorated through years three and four. Interestingly, the variance of responses (not shown here due to space limitations) does not reflect a significant year-related effect. Figure 4 arguably shows that (statistically) students have a mild but fairly constant level of disagreement with the statement posed in Q4, that is students appear to feel that they may be able to solve unfamiliar problems but they have no strong conviction that they will probably be able to do so.

Interestingly, Q6 and Q5 show a small decline in perceptions. Q6 is likely to represent student's opinion of their individual confidence in their problem-solving abilities – their self-efficacy (Belski, et al., 2011). The data suggests that the future-directed self-efficacy reflected in responses to Q6 differs much from the historical self-confidence measure of Q1. Q1 (I am very good at problem-solving) reflects an aggregated perception of past successes, and very likely also perception of how the respondent sees their performance relative to that of peers. The average of all responses to Q1 showed general increase in confidence over time, however the average of all responses to Q5 and Q6 both show decline followed by some improvement after year 2 or year 3. There are differences between response data for different Schools which may reflect some School-specific differences, or simply statistical variation arising from limited sample size. It seems that future-directed self-efficacy in resolving problems does not improve significantly or at all over four years of university study. That is, despite up to four years of study in engineering programs students appear to believe that they have not learned or been taught HOW to resolve problems in a broad and systematic way that they believe they can rely on.

What activities improved students' problem-solving skills the most?

The qualitative student responses to Q8 ("What methods and approaches used by your RMIT teachers (so far) improved your engineering problem-solving skills the most?") were grouped into a small range of categories that appeared to reasonably characterise those responses. Almost all responses cited just one method/approach. Those categories were:

- PBL – including both Project Based Learning and Problem Based Learning as described by the student as a key mechanism for developing their problem-solving skills. (e.g. a 3rd year student comment: "Major projects are a good approach to improve these skills. Weekly progress meetings with the lecturer are a great way to brainstorm and develop a deeper understanding.")
- Group work – where students indentified working with others primarily formally as part of an assessed activity but also including informal group work (as in a study group). (e.g. a 1st year student commented: "Peer tutorial sessions probably help the most in developing problem-solving skills")
- Practice foundations – being required by the academic to do regular problem-solving at a low to mid-level of difficulty through which solution patterns could be learned (e.g. a 1st year student

commented: “Repetition. Lecturer's and tutors make themselves available to extra help if you need it.”)

- Method – where the academic emphasised to the students a methodological approach such as simplifying a problem or explained the concepts well. That is, the academic conveyed concepts and problem-solving approaches with clarity.
- Guided problem-solving – the academic provided challenge to the student which forced them to think through the issues, and was available to provide guidance (but not answers) when the student was unable to progress the solution. (e.g. a 4th year student comment: “One on one help. Worked examples to similar (but not the same) problems helped. i.e. seeing a method used in one context I can then apply it to another context.”)
- “Other” – the student was able to identify an approach that worked for them but which didn’t fit in with any of the five categories above
- “No idea” – the student was not able to identify any approach

Table 2 presents student responses to Q8.

Table 2. Analysis of response to Q8, by category and experience level

CATEGORY	YEAR 0 (Y0)	Y0 ranking of importance	YEAR 1 to YEAR 4 (Y1-Y4)	Y1-Y4 ranking of importance	Change in ranking
"PBL"	3%	7	20%	3	4
"Groupwork"	6%	6	4%	7	-1
"Practice foundations"	11%	5	6%	6	-1
"Other"	13%	4	22%	2	2
"Method"	18%	3	14%	4	-1
"No idea"	21%	2	10%	5	-3
"Guided problem-solving"	27%	1	25%	1	0

The category “Guided problem-solving” is the most common response for both groups, with about 25% of each group citing this approach. It is interesting to note that with additional experience as engineering students PBL was recognised as substantially more important as a platform for learning problem-solving skills. It was also clear that the “Other” category was cited more frequently by experienced students, suggesting that with maturity more students were able to articulate alternative approaches that they had determined work for them. Supporting this interpretation was the reduced frequency of “No idea” cited amongst the Year 1 to Year 4 group.

Discussion

This study revealed a number of interesting findings. First of all, it was unable to establish a substantial difference in perceptions of graduates from different engineering school of their problem-solving abilities. Both the primarily traditional educational approach of SAMME and SECE, and the PBL-rich strategy of SCECE, equipped their graduates’ with similar levels of problem-solving self-efficacy (Q6) and peer-related standing in problem-solving (Q1). As expected, the latter (peer-related standing) was boosted over the four years of engineering degree. The behaviour of the former (problem-solving self-efficacy) was unexpected – it actually dropped. Although this drop in self-efficacy was not statistically significant, it indicates the urgent need to focus closely onto teaching problem-solving explicitly and consider offering compulsory course specifically focused on methodologies of engineering problem-solving (Belski, 2009; Belski, et al., 2011).

Students’ opinions on the methods and approaches used by your RMIT teachers that improved engineering problem-solving skills the most identified some directions towards improvement of engineering curriculum. First of all, the superiority of *guided problem-solving* versus *practice foundations* was somewhat unexpected. It seems that this superiority has been suggested by Sweller on numerous occasions, when he reported on primacy of worked examples over routine problem-solving activities for acquiring problem-solving strategies by novices (Sweller, 1988; Sweller & Cooper, 1985). This finding suggests that engineering academics may need to focus on engaging students (at least in the first two years of the degree) in studying worked examples, rather than directing students to devote significant time to routine problem-solving. Secondly, students told us that *groupwork*, which is often considered by engineering academics to be vital in developing problem-solving skills does not really impact their problem-solving abilities. Thirdly, the *PBL* category encountered significant increase over the university years. This is a good indication of student-perceived effectiveness of PBL in enhancement of problem-solving skills, and for this reason PBL needs to be seriously considered, at least in the last two years of study. Students who had been exposed to the PBL-rich curriculum in SCECE did not perceive that they had developed greater strength in problem-solving than students in other Schools, presumably as they had no basis for comparison across Schools but only relative to peers in the same programs. Lastly, the reduction of mentioning of the *method* category may be related to the drop of problem-solving self-efficacy discussed above.

References

Amabile, T. M. (1983). The Social Psychology of Creativity: A Componential Conceptualization. *Journal of Pelsonality and Social Psychology, 45*(2), 357-376.

Australian Technology Network. (2000). *Generic Capabilities of ATN University Graduates*.

Bandura, A. (1977). Self-efficacy: Toward a Unifying Theory of Behavioral Change. *Psychological Review, 84*(2), 191-215.

Belski, I. (2009). Teaching Thinking and Problem-solving at University: A Course on TRIZ. *Creativity And Innovation Management, 18*(2), 101-108.

Belski, I., Baglin, J., & Harlim, J. (2011). Teaching TRIZ at University: a Longitudinal Study. *International Journal of Engineering Education*.

DEST. (2002). *Employability skills for the future*. Canberra: Australian Chamber of Commerce and Industry and the Business Council of Australia for the Department of Education, Science and Training.

Engineers Australia. (2009). *Australian Engineering Competency Standards - Stage 1*.

Graduate Careers Australia. (2007). *Graduate Course Experience 2007*. Melbourne: Graduate Careers Australia.

Harlim, J., & Belski, I. (2010). *Young engineers and good problem-solving: The impact of learning problem-solving explicitly.* Paper presented at the 21st Annual Conference for the Australasian Association for Engineering Education, Sydney, Australia.

National Academy of Engineering. (2005). *Educating the engineer of 2020: adapting engineering education to the new century*. NY: National Academies Press.

Simon, H. A. (1996). *The sciences of the artificial* (3 rd. ed.). Cambridge: MIT.

Sweller, J. (1988). Cognitive Load During Problem-solving: Effects on Learning. *Cognitive Science, 12*, 257-285.

Sweller, J., & Cooper, G. A. (1985). The use of worked examples as a substitute for problem-solving in learning algebra. *Cognition and Instruction*(2), 59-89.

Copyright statement