Exploring differences in perceived problem-solving and creativity skills between novice and experienced engineering students

Andrew Valentine[a] and Iouri Belski[b]
Department of Electrical, Electronic and Computer Engineering, The University of Western Australia[a], School of Engineering, RMIT University[b]
Corresponding Author Email: andrew.valentine@uwa.edu.au

Introduction

Problem-solving and creativity are key skills of the engineering profession. Engineering employers place high value on their employees being able to solve problems effectively and on being able to demonstrate creativity when doing so (Nair, Patil, & Mertova, 2009; Ramadi, Ramadi, & Nasr, 2016). Despite the importance of these skills, it is unclear how engineering curricula prepare graduates for using these skills in the workplace. Studies consistently report that graduates do not meet employers' competency expectations in these areas (Nair et al., 2009; Ramadi et al., 2016).

Concerningly, engineering students consistency report a lack of confidence in their creativity skills. For example, first-year students from Hong Kong only slightly positively agreed they were competent to solve engineering problems and generate new ideas (Chan, Zhao, & Luk, 2017), suggesting awareness of the need to improve these skills. Similarly, first-year Australian engineering students have shown low disposition towards creativity (Gardner, Goldfinch, & Willey, 2017) suggesting that building creativity skills is important. In workshops, second year students at an Australian tertiary institution expressed concern that they had insufficient creativity for engineering (Male & Bennett, 2015). Analysis of responses from the 2018 Australian Graduate Outcome Survey (GOS) (completed by 43% of local graduates four months after their graduation (QILT, 2019)) revealed that 89% of engineering students felt that their studies had built their "ability to solve problems" but only 67% of engineering students felt that their studies had built their "ability to develop innovative ideas" (Bolton & Jackson, 2019, p. 26). These findings suggest that a clear majority of engineering graduates perceived their studies were effective at building problem-solving skills, but many graduates perceived their studies did not provide emphasis on building creativity-related skills.

Problem-solving in an effective and creative way is underpinned by possession of appropriate domain-relevant skills, high self-efficacy and motivation towards the task being faced, and creativity skills (Amabile, 1983; Bandura, 1977; Harlim & Belski, 2010). Steiner et al. (2011) found that while engineering students' perception of their own problem-solving skills increased between first and fourth year, their problem-solving self-efficacy decreased over the same time period. This is problematic as possession of self-efficacy is imperative to successful long-term development of problem solving skills (Harlim & Belski, 2013), and highlights the need to do more in building students' self-efficacy.

While some studies have reported a measured increase in engineering students' creativity and innovation skills between first and fourth years of study in design-related tasks (Nazzal, 2015; Williams, 2013), others have reported a measured decrease in performance when completing design-related tasks (Genco, Hölttä-Otto, & Seepersad, 2012; Valentine, Belski, & Hamilton, 2018). Also related to design, Davis and Amelink (2016) report that fourth-year engineering students were more confident in their ability to design innovative solutions than first-year students. On the other hand, Sola, Hoekstra, Fiore, and McCauley (2017) found that fourth year engineering students were less creative than first year students, based on the Test for Creative Thinking-Drawing Production. These outcomes demonstrate that there is no clear answer regarding how students' creativity skills may change during their studies.

Studies also report that students' perception of creativity may change as they progress through their degree. For example, a recent longitudinal study from the US found that engineering students' creative identity (whether creativity is an important part of their selfimage) and creative self-efficacy remained consistent between first and fourth year of study (Zappe & Tise, 2019), but there was a perception among students of a decreasing expectation to do creative work in class (Zappe & Tise, 2019). Likewise, Canadian students' perception of the value of creativity has been found to decrease between third and fourth year of study (Waller & Strong, 2017). These findings suggest that students' expectation of having to be creative as an engineer may decline during their studies, and may be linked to perceptions of their own skills.

The previously discussed literature highlights the need for further research to investigate and clarify Australian engineering students' perception of the influence of their studies on their creativity and problem-solving skills. In order to be creative and efficient at problem-solving, it is necessary that students value these skills and possess high self-efficacy in these areas. This study builds upon previous work by Steiner et al. (2011) and Becattini and Cascini (2016), and focused on identifying how students' perceptions of their problem-solving and creativity skills, changed over the course of studying an undergraduate engineering degree. This study addressed two research questions:

To what extent do engineering students perceive themselves as being better at problem-solving as a result of studying a formative (four or five-year) engineering program?

To what extent do engineering students perceive themselves as being more creative as a result of studying a formative (four or five-year) engineering program?

Methodology

The data presented in this study were collected in a survey of engineering students at two tertiary institutions in Australia. Comparing responses between students who had recently commenced their engineering studies and students who had been studying for several years provided means to understand how students' perception of their creativity and problem-solving skills changes during an engineering degree. Human research ethics approval was obtained. The survey was administered online using Qualtrics™.

Participants

Table 1: Description of Survey Participants

University	Year Level	Data Collection Period	Participant Recruitment	Unit Type	N	Response Rate (% of class)
University A	First-year under-graduate (UG)	2018 Semester 1	Notice Posted on Learning Management System (LMS)	Eng. Design - Common (EWB Challenge)	212	30%
University A	Fourth-year UG	2019 Semester 1	Notice Posted on LMS	Capstone Part A	92	15%
University B	First-year UG	2019 Semester 1	Invitation in-class at start of lecture	Eng. Design – Common (EWB Challenge)	214	52%
University B	Second-year post-graduate	2019 Semester 2	Invitation in-class at start of lecture	Eng. Design – Electrical & Electronic	29	19%
				Eng. Design - Mechanical	28	22%

Participants were engineering students enrolled at two tertiary institutions (University A and University B) in Australia (Table 1). University A was in the Australian Technology Network and University B was one of the Group of Eight research-intensive universities in Australia.

Participants from University A were engineering students in their first year of undergraduate study or fourth year of undergraduate study, completing engineering design units. An invitation to participate in the survey was posted on the Learning Management System for each of the respective units. Of those who participated, four first-year and two fourth-year students did not respond to all questions and were excluded from analysis. This resulted in 212 valid first-year student responses and 72 fourth-year student responses. The sample set of first-year students were 165 males, 45 females, 2 other. The sample of fourth-year students were 72 males, 20 females.

Participants from University B were engineering students enrolled in engineering design units, in either first year of undergraduate study or second year of postgraduate study. The first-year unit was a common engineering unit. The two postgraduate units were in the disciplines of mechanical, and electrical & electronic engineering. In each unit, students were invited to complete the survey at the beginning of a lecture (only once in each unit). Three first-year undergraduate and three postgraduate students who participated in the survey did not respond to all the questions and were excluded from analysis. Twenty-four postgraduate students who did not complete their undergraduate degree at the University B prior to commencing their postgraduate studies, were also excluded from analysis (16 from electrical & electronic engineering, 7 from mechanical engineering, 1 other). This resulted in 212 first-year valid student responses and 57 postgraduate valid student responses. The sample set of first-year students were 162 males, 47 females, 5 not stated. The sample of postgraduate students were 51 males, 6 females.

Survey Instrument

The survey items (Table 2, 3) were amended from the questionnaire used by Steiner et al. (2011) and Becattini and Cascini (2016). The questionnaire included several demographic questions. Questions 1 to 3 measured students' perception of their own creativity and idea generation skills. These questions required participants to reflect on their idea generation efficacy (related to fluency), their ability to generate good ideas (related to quality), and their ability to think imaginatively (related to originality). Fluency, quality, and originality are widely used metrics for evaluating creativity (Cropley, 2000). Questions 4 to 6 measured students' perception of their own problem-solving skills and attitudes towards problem-solving, and were directly adopted from the survey administered by Steiner et al. (2011).

Postgraduate students at University B were also asked whether they had completed an undergraduate degree at University B prior to commencing their postgraduate studies. This allowed students who had not completed all of their tertiary engineering studies at the same institution to be excluded from analysis, to remove this confound from the findings.

Results

Table 2: Descriptive Statistics of University A First- and Fourth-Year UG Student Responses

	First-Year (*N* = 212)		**Fourth-Year (*N* = 92)**		
	M	***SD***	***M***	***SD***	**Difference**
1. I am good at coming up with new ideas	2.16	0.62	1.96	0.80	+0.20**
2. I have a lot of good ideas	2.34	0.60	2.14	0.75	+0.20*
3. I have a good imagination	2.00	0.71	2.05	0.89	-0.05
4. I am very good at problem solving	1.97	0.65	1.85	0.71	+0.08
5. I am certain that I am able to resolve any problem I will face	2.61	0.81	2.23	0.90	+0.38***
6. So far, I have resolved every problem I faced	2.91	0.89	2.48	1.00	+0.43***

Notes. Students rated their agreement on a 5-point scale (1 = *Strongly Agree*; 5 = *Strongly Disagree)*; *p<.05, **p<.01, ***p<.001

Participants' responses were analysed using SPSS 23^{TM}. Students demonstrated various levels of positive agreement with questions 1 to 5 (Table 2, Table 3). On the other hand, students a University B showed disagreement with question 6. At each university, students' perception of their ability to come up with new ideas, come up with good ideas, being good at problem solving, and being able to resolve problems they will face all increased, although sometimes to quite differing levels. In contrast, findings were mixed between institutions regarding having a good imagination (University A went slightly down, University B went slightly up), and whether they had resolved every problem they had faced (University A went up, University B remained similar).

Table 3: Descriptive Statistics of University B First-Year UG and PG Student Responses

	First-Year (*N* = 214)		Postgraduate (*N* = 57)		
	M	***SD***	***M***	***SD***	**Difference**
1. I am good at coming up with new ideas	2.22	0.69	2.05	0.69	+0.17
2. I have a lot of good ideas	2.41	0.66	2.05	0.72	+0.36***
3. I have a good imagination	2.14	0.90	2.02	0.79	+0.12
4. I am very good at problem solving	2.10	0.72	1.93	0.62	+0.17
5. I am certain that I am able to resolve any problem I will face	2.83	0.95	2.79	1.10	+0.04
6. So far, I have resolved every problem I faced	3.16	1.01	3.18	1.02	-0.02

Notes. Students rated their agreement on a 5-point scale (1 = *Strongly Agree*; 5 = *Strongly Disagree)*; **p*<.05, ***p*<.01, ****p*<.001

Shapiro-Wilk tests of normality demonstrated that the distribution of responses to each question for both year levels at both universities was not normal (p < 0.001). Therefore, non-parametric tests of significance were adopted to check for differences between the groups. For University A, The Mann-Whitney U Test of significance showed there were statistically significant differences between the first- and fourth-year students regarding coming up with new ideas (z = -3.005, p =.003), having good ideas (z = -2.380, p = .017), problem-solving self-efficacy (z = -3.642, p < .001), and having resolved every problem faced (z = -3.572, p < .001). There were no significant differences for having a good imagination (z = -0.078, p = .939), and being good at problem-solving (z = -1.780, p = .076). For University B, The Mann-Whitney U Test of significance showed there was only a statistically significant difference for having good ideas (z = -3.598, p <. 001). There were no statistically significant differences for coming up with new ideas (z = -1.882, p = 0.060), having a good imagination (z = -0.966, p = 0.334), being good at problem-solving (z = -1.780, p = 0.076), problem-solving self-efficacy (z = -0.328, p = 0.744), or having resolved every problem faced (z = -0.069, p = 0.946).

Discussion and Implications

The findings in Tables 2 and 3 highlight that students at University A and B felt they were only slightly better at problem-solving after completing several years of study. Although there was a slight increase in perception of problem-solving ability, the difference was not statistically significant, unlike Steiner et al. (2011) who found a significant increase.

Students at University A reported having significantly higher problem-solving self-efficacy (Q5) and had been more effective at resolving problems (Q6) after completing several years of study. Both of these findings varied from those previously identified by Steiner et al. (2011) who found that students' problem-solving self-efficacy (Q5) and effectiveness at resolving problems (Q6) both declined (through not significantly). This suggests that efforts to address problem-solving skills may have been successful in this regard. However, these outcomes were not repeated at University B where problem-solving self-efficacy (Q5) and past effectiveness at resolving problems (Q6) remained very similar after several years of study.

In this study, students at University A were surveyed towards the beginning of fourth-year, while Steiner et al. (2011) surveyed students at the end of the degree program. In this study, it is likely that majority of participants (70%) had not yet done a design course where they had to build a product practically on their own. Students with limited experience of being primarily responsible for building a product on their own (e.g. capstone project) or have limited experience of involvement in real workplace projects, may have over-evaluated their abilities originally (Belski, Skiadopoulos, & Yang, 2019), which may change after such experiences. Reflecting on the first research question, it is unclear to what extent completing several years of study in an engineering degree influences students' *perception* of their problem-solving abilities. Many responses at University B remained very similar, and while there were some notable increases at University A, it was not common across all questions. Considering the 2018 GOS results, it is clear that students perceive their studies help build their ability to solve problems, but this was not readily observed in this study. It is important to note that students' problem-solving skills undoubtedly increase over studying an engineering degree, but their self-perceptions may not accurately reflect their skills.

Reflecting on the creativity-related questions (1 to 3), the results shown in Tables 2 and 3 highlights that all four groups of students agreed (Likert Scale less than 3) that they were good at coming up with new ideas, have a lot of good ideas, and have a good imagination. In addition, students' perception of their ability to come up with ideas increased (+0.20 and +0.36) between first and later years of study, as did their perception of having good quality ideas (+0.20 and +0.29). In contrast, students from University A reported a slight decrease (-0.05) regarding having a good imagination, while students from University B reported an increase (+0.12), showing conflicting results. Moreover, many of the changes were statistically insignificant, and only question 2 demonstrated a statistically significant increase for both University A and University B. Reflecting on the second research question, the findings suggest that overall, students perceive themselves as being slightly more creative as a result of studying a four or five-year formative engineering program in certain ways, but there is a lack of strong evidence to support this. Arguably, this finding is similar to that of the 2018 GOS where only a slight majority of students perceived their studies had enhanced their ability to develop innovative ideas.

It is possible that these perceptions may stem from the lack of content dedicated to teaching creativity-related skills in engineering curricula which has been previously reported (Daly, Mosyjowski, & Seifert, 2014; Marquis, Radan, & Liu, 2017; Valentine, Belski, Hamilton, & Adams, 2019). Indeed, it has been reported that engineering students perceive their degree may do little to encourage or develop creative skills (Carpenter, 2016), that engineering students perceive there is limited integration of creativity in the curricula (Gaudron & Kövesi, 2017; Kazerounian & Foley, 2007), and that that engineering students may perceive that their instructors do not value creativity even when their instructors report trying to develop students' creative skills (Kazerounian & Foley, 2007).

How can we improve creativity-related skills in engineering education?

Educators may need to do more to purposefully focus on building engineering students' creativity-related skills, including making students aware when this is an intended outcome, and making students aware how this is achieved in the course. This is critical for students to start seeing creativity as part of their identity and to gain self-efficacy in this area. Including courses focused on teaching these skills in engineering programs is one possibility (e.g. Becattini and Cascini (2016)), but may not be practical in already crowded curricula. Integrating creativity training activities into existing courses throughout a degree (such as design courses) is another possibility. For example, short creativity activities which students can learn in under an hour can have measurable benefits after three months (Valentine, Belski, & Hamilton, 2016), while longer sessions of planned creativity training can have measurable long-term benefits after several years (Birdi, Leach, & Magadley, 2012). Engaging students in appropriate project- and problem-based learning can also be an effective way to build creativity skills.

Overall, it is recommended that educators consider how their courses might be able to build creativity skills as part of the *intended learning outcomes*. This may help to overcome the competency gaps reported by engineering employers (Nair et al., 2009; Ramadi et al., 2016) and further improve students' skills to meet the needs of Australian engineering industry.

Limitations

Results of the study may vary depending on the context, and may change if conducted at other institutions or in different countries. Comparison between first and later-year students was not completed using the same students, meaning the findings were not longitudinal.

Acknowledgements

The authors would like to thank Sally Male and Andrew Guzzomi from The University of Western Australia for their support and helpful suggestions during the project.

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