TRIZ Heuristics Improve Creative Problem Solving Self-efficacy of Engineering Students

Iouri Belski[a], Anne Skiadopoulos[a], Yang, Chi Tin Stephen[b]
RMIT, Australia[a], VTC, Hong Kong[b]
Corresponding Author's Email: iouri.belski@rmit.edu.au

Introduction

Although, some authors reported on successes in development of creative problem-solving skills (Becattini & Cascini, 2016; Belski, Baglin, & Harlim, 2013), numerous studies suggest that engineering education has not yet been able to instil the skills of creative problem-solving effectively (Daly, Mosyjowski, & Seifert, 2014; Gaudron & Kövesi, 2017; Sola, Hoekstra, Fiore, & McCauley, 2017; Steiner et al., 2011).

Moreover, it seems that creative problem-solving is not yet on the agenda of many engineering schools. In 2017, Valentine, Belski, Hamilton and Adams (2019) analysed online publicly accessible course outlines of 1109 compulsory courses from 42 degree programs that were accredited by institutes of engineering in Australia and New Zealand. It was found that explicit articulation of creativity-related learning goals by course outlines was poor, and practically limited to the first year courses of engineering study (Valentine et al., 2019).

Based on the analysis of studies that demonstrated students' creative problem-solving skills increased after being introduced to heuristics of Theory of Inventive Problem Solving (TRIZ) (Blicblau & Ang, 2017; Shukhmin & Belski, 2017; Smith, Belski, Brown, & Kalyvas, 2018), Belski & Belski (2018) posited that creativity skills of engineering students can be enhanced by scheduling one or two classes of already existing courses to introduce a heuristic that suits the content of each particular course.

The above-mentioned studies by Blicblau & Ang, Shukhmin & Belski and Smith et al. engaged full-time (FT) students that had either just started engineering degree, or that were in the engineering diploma program. They reported on improvements of students' self-efficacy in creative problem solving as a result of embedding TRIZ heuristics into existing courses. This study planned to evaluate the influence of TRIZ heuristics on full-time and part-time (PT) students that have already completed two years of engineering degree.

Hypothesis 1: Introduction of TRIZ heuristics will significantly improve creative problem-solving self-efficacy of third-year engineering students.

Hypothesis 2: FT and PT student will be influenced by the TRIZ heuristics in a similar way.

Methodology

One hundred and forty-three students that were enrolled in a BEng. (Electrical) degree offered by an Australian university in Hong Kong were involved in this study. Students were in the first trimester of a third-year two-trimester team-based design course. During this first trimester students had to develop product ideas and start building their team products that had to be demonstrated at the end of the second trimester. All the students graduated from the Hong Kong Vocational Training Council (VTC) with the Higher Diploma in Electrical Engineering (HDEE). Sixty students were enrolled on full-time basis (FT), 83 – as part-time (PT). All PT students were full-time employed. The average time of industrial experience for FT students was 0.5 years. PT students spent five years with industry on average.

Two and a half hours of lecture classes in weeks 2, 3 and 4 of the study trimester were devoted to introduction of four TRIZ heuristics. Classes for FT students were conducted during a day time and were followed by evening classes for PT students. Class attendance of FT students exceeded 90%. Only around 60% of PT students attended their classes. Each heuristic was introduced to the students during a class by showing them a short introductory video from the TRIZ Repository (www.edisons21.com). Video viewing was followed by a discussion on the application of each heuristic. All classes were conducted by the same lecturer. Students were asked to consider using TRIZ heuristics in their course project work. This usage was not compulsory. Knowledge of the TRIZ heuristics was not assessed and did not influence course marks. It was expected that students will reflect on learning TRIZ heuristics in their study journals.

In order to establish changes in creative problem-solving self-efficacy, students were surveyed twice: at the beginning of a course and at the end of it. Survey results were analysed with IBM SPSS. Both surveys were web-based and were conducted with Qualtrics.

The first survey contained 22 questions; the second – 32. Both surveys were similar to the surveys administered in the study by Smith, Belski, Brown and Kalyvas (2018). Surveys asked students to agree to participate in the research study and collected students' demographic information (age, gender, mode of study, years in industry, etc.). They also consisted of numerous statements related to students' perceived creativity and problem-solving skills. Ten additional questions of the second survey intended to identify students who attended the classes that introduced TRIZ heuristics and also to establish their opinions on the effectiveness of these heuristics for developing creative solutions.

Invitation to participate in the surveys were posted as an announcement at a learning management system (Canvas). The first survey was announced early in week 1 of a trimester and was closed in week 2, just prior to the first TRIZ class. At the end of the trimester, students were able to participate in the second survey. It was open for nearly three weeks. Survey participation was not compulsory.

Fifty-eight students participated in the first survey, 81 – in the second. Thirty-nine students that participated in the first survey indicated their enrolment in full-time study, 19 – in part-time. Forty-four of the second survey participants stated being FT students, 37 – being PT students. Two students identified themselves as female in each of the surveys. Fifty-five students identified themselves as male in the first survey; 78 – in the second. Most of the FT students that participated in both surveys were younger than 22; most of the PT students were older than 25.

TRIZ Heuristics

Students were introduced to four TRIZ heuristics: Situation Analysis (SA), Resources, Size-Time-Cost Operator (STC) and 8 Fields of MATCEMIB. Although all these four heuristics can assist a practitioner to develop creative solution ideas, they are beneficial at different stages of engineering problem solving. SA and STC are the most useful during the stage of problem definition. They aid in comprehending the problematic situation more adequately and in framing and reframing the problem. Heuristics of Resources and 8 Fields of MATCEMIB suit the idea generation stage the most. These two heuristics can help not only to generate novel ideas, but also to establish resources that are available for delivering these novel ideas.

The heuristic of Situation Analysis engages a user in answering 11 questions that are intended to clarify the functions that demand improvement and to separate human-related needs from technical needs (Belski, Teng, Belski, & Kwok, 2016; OLT Fellowship, 2016). The STC heuristic guides a user in viewing the problematic situation from different perspectives. It expects a practitioner to consider the situation under six unrealistic conditions (i.e. Size of the improved product being zero or infinity; Time to improve the product equals zero or infinity; and Cost of improving the product being zero or infinity) (OLT Fellowship, 2016).

The 8 Fields of MATCEMIB heuristics suggests contemplating solution ideas that have different principles of operation (i.e. Mechanical, Acoustic, Thermal, Chemical, Electric, Magnetic, Intermolecular and Biological – MATCEMIB). In essence, it helps a user to manually search her/his knowledge database.

The heuristics of Resources proposes to identify the resources that are available under the circumstances and suggests searching for seven kinds of resources (i.e. Substance, Energy, Information, Time, Space, Function and System).

Results

Table 1 depicts statistical comparison of student survey responses to four statements (questions) that were used in the study by Smith et al. (2018). Questions 1 and 2 reveal subjects' idea generation self-efficacy. Questions 3 and 4 display their problem-solving self-efficacy. Analysis of all four questions together allow to establish changes in students' creative problem-solving self-efficacy.

Table 1 presents the Means and standard deviations (SD) of the responses to four identical questions from both surveys in three individual sections. The first section (left) depicts responses of all students. The second (middle) section – responses of FT students. The last (right) section – replies of PT students. For every question in each section in Table 1 students are divided into three groups. The Pre-TRIZ group combines the respondents of the first survey that was conducted prior to students' exposure to TRIZ heuristics. The TRIZ-4 group unites the students that participated in the second survey and indicated learning all four heuristics. The TRIZ-03 group combines the subjects of the second survey that admitted either to being exposed to one, two or three TRIZ heuristics or to not being aware of such heuristics at all.

Table 1: Comparison of survey responses

(Likert scale of 5, 1 - Strongly Agree, 5 - Strongly Disagree)

Question	Group	All Students			Full-Time Students			Part-Time Students		
		N	Mean	SD	N	Mean	SD	N	Mean	SD
Q1: I am good at coming up with new ideas	Pre-TRIZ	57	2.51	0.710	39	2.38	0.711	17	2.82	0.636
	TRIZ-03	24	2.63	0.824	7	2.57	0.787	18	2.67	0.840
	TRIZ-4	56	***2.23***	0.632	37	2.30	0.618	19	***2.11***	0.658
Q2: I have a lot of good ideas	Pre-TRIZ	58	2.64	0.718	40	2.53	0.751	17	2.94	0.556
	TRIZ-03	24	2.67	0.637	7	2.71	0.488	18	2.61	0.698
	TRIZ-4	56	***2.29***	0.706	37	2.35	0.633	19	***2.16***	0.834
Q3: I am very good at problem solving	Pre-TRIZ	57	2.51	0.630	39	2.38	0.590	17	2.76	0.664
	TRIZ-03	24	2.50	0.590	7	2.57	0.535	18	2.56	0.705
	TRIZ-4	55	**2.24**	0.693	36	2.39	0.728	19	**1.95**	0.524
Q4: I am certain that I am able to resolve any problem I will face	Pre-TRIZ	57	2.49	0.630	39	2.26	0.498	17	*3.00*	0.612
	TRIZ-03	24	2.58	0.654	7	2.86	0.900	17	2.47	0.514
	TRIZ-4	55	2.33	0.818	37	2.51	0.870	18	***1.94***	0.539

The results of the t-tests with statistical significance to 5% between specific groups are shown in Table 1 by use of **bold** font, *italic* font and by underlining the mean values. The mean of the TRIZ-4 group in any of individual sections shown in **bold** font identifies statistically significant difference between the mean of the TRIZ-4 and Pre-TRIZ groups. The mean of the TRIZ-4 group in any of individual sections shown in *italic* font identifies statistically significant difference between the mean of the TRIZ-4 and TRIZ-03 groups. When the mean of the TRIZ-4 group is both bolded and italicised, it indicates statistically significant difference between the TRIZ-4 group and each of the other two groups for the same question in the same section. The underlined means display statistically significant difference between the responses to the same question by the students from the FT and PT sections (e.g. 2.38 versus 2.82 for Pre-TRIZ for Q1).

All students

When FT and PT students were considered together, the t-test revealed a statistically significant change in their perceptions on three out of the four survey questions as a result of introduction of all four TRIZ heuristics (Q1, Q2, and Q3). Students who studied all four heuristics (TRIZ-4 group) thought of their creative problem-solving skills more positively than the participants of the first survey (Pre-TRIZ group). As a result of studying four TRIZ heuristics, students' perception of their idea generation abilities improved significantly (Q1: from 2.51/5 to 2.23/5, with Cohen d=0.62; Q2: from 2.64/5 to 2.29/5, d=0.50). Similar improvement occurred with their perceptions on problem-solving abilities (Q3: change from 2.51/5 to 2.24/5, d=0.41; Q4: from 2.49/5 to 2.33/5, d=0.22).

Responses to the two questions related to the idea generation self-efficacy (Q1 and Q2) showed statistically significant difference in perceptions of students from the TRIZ-4 and TRIZ-03 groups. Students from the TRIZ-4 group had higher opinion on their creative problem-solving abilities than students from the TRIZ-03 group (Q1:2.23/5 vs 2.63/5, d=0.58; Q2: 2.29/5 vs 2.64/5, d=0.50).

It is important to note that for some reason students from the TRIZ-03 group perceived their creative problem-solving abilities as worse (Q1, Q2 and Q4) or practically identical (Q3) to that of the students from the Pre-TRIZ group. Neither of the differences between the responses of the TRIZ-03 group and the Pre-TRIZ group were statistically significant.

Pearson correlations (2-tailed) between the number of heuristics studied and students' responses to the four questions shown in Table 1 were calculated. Statistically significant correlations were identified for all questions except Q4. All statistically significant correlations were negative with values in a range of $-0.337<r<-0.271$.

Full-time students

As shown in Table 1, no statistically significant differences were found between student responses to the same questions by FT students.

There are interesting tendencies that can be seen in the responses of FT students. Students who studied three or less TRIZ heuristics (TRIZ-03 group) perceived their creative problem-solving abilities being at a lesser level than the students that participated in the first survey (Pre-TRIZ group) (Q1, Q2, Q3 and Q4). Students from the TRIZ-4 group felt that their idea generation skills (Q1 and Q2) were slightly better than that of their Pre-TRIZ group. Students from the TRIZ-4 group assessed their problem-solving skills as either similar to (Q3) or worse than (Q4) that of their colleagues from the Pre-TRIZ group.

Pearson correlations (2-tailed) between the number of heuristics studies by FT students and their responses to the four questions shown in Table 1 were not statistically significant.

Part-time students

Data in Table 1 suggest that the PT students were substantially influenced by the TRIZ heuristics. The t-test identified a statistically significant change in their perceptions for all four survey questions as a result of introduction of all four TRIZ heuristics. Students who studied all four heuristics (TRIZ-4 group) thought of their creative problem-solving skills statistically significantly more positively than their Pre-TRIZ group colleagues and the students from the TRIZ-03 group.

As a result of studying four TRIZ heuristics, PT students' perception on their idea generation abilities improved significantly (Q1: from 2.82/5 to 2.11/5, d=1.13; Q2: from 2.94/5 to 2.16/5, d=1.12). Similar improvement occurred in their perceptions on problem-solving abilities (Q3: change from 2.76/5 to 1.95/5, d=1.40; Q4: from 3.00/5 to 1.94/5, d=1.90).

Data in Table 1 also indicate the improvement in perceptions on creative problem-solving abilities for all student who studied less than four TRIZ heuristics (TRIZ-03 groups).

Pearson correlations (2-tailed) between the number of heuristics studies by PT students and their responses to the four questions shown in Table 1 were statistically significant. All correlation coefficients were negative with values in a range of -0.562<r<-331.

Full-time versus part-time students

Comparison of survey responses of FT and PT students shown in Table 1 reveals that they had statistically significant differences in perceptions on their creative problem-solving abilities both before the course and as a result of studying four TRIZ heuristics.

FT versus PT students: before the course

Before the course, PT students evaluated their idea generation abilities much lower than their FT peers (Q1: 2.82/5 for PT vs 2.38/5 for FT, d=0.65; Q2: from 2.94/5 vs 2.53/5, d=0.6). Similarly, PT students thought of their problem-solving skills less favourably than FT students (Q3: 2.76/5 vs 2.38/5, d=0.63; Q4: 3.00/5 vs 2.26/5, d=1.41).

FT versus PT students: after the course

The course changed perceptions of FT and PT students in a very different way. As shown in Table 1, PT students improved their perceptions on their creative problem-solving abilities as a result of the course. This change was statistically significant for the students that studied all four TRIZ heuristics (TRIZ-4 group) and not statistically significant for students who studied three or less heuristics (TRIZ-03 group).

Change in FT students' perceptions on their creative problem-solving skills was complicated. FT students who studied less than four heuristics (TRIZ-03 group) lowered opinions on their creative problem-solving abilities (Q1 - Q4). FT students who studied all four heuristics (TRIZ-4 group) showed mixed perception changes. Their opinions on the idea generation skills improved a little (Q1 and Q2). At the same time, their perceptions on problem-solving abilities as a result of taking the course either declined (Q4) or stayed the same (Q3).

Comparison of opinions of PT and FT students who studied all four TRIZ heuristics showed statistically significant differences in perceptions on problem-solving skills (Q3: 1.95/5 for PT vs 2.39/5 for FT, d=0.67; Q4: 1.94/5 vs 2.51/5, d=0.86). Although the opinions of PT students that studied all four heuristics on idea generation abilities were more positive than that of their FT peers, the differences were not statistically significant (Q1: 2.82/5 for PT vs 2.11/5 for FT, d=0.31; Q2: from 2.16/5 vs 2.35/5, d=0.27).

Figure 1 presents a graphical representation of changes in survey responses of students to Q3 (Table 1) that are related to the number of heuristics they have learnt.

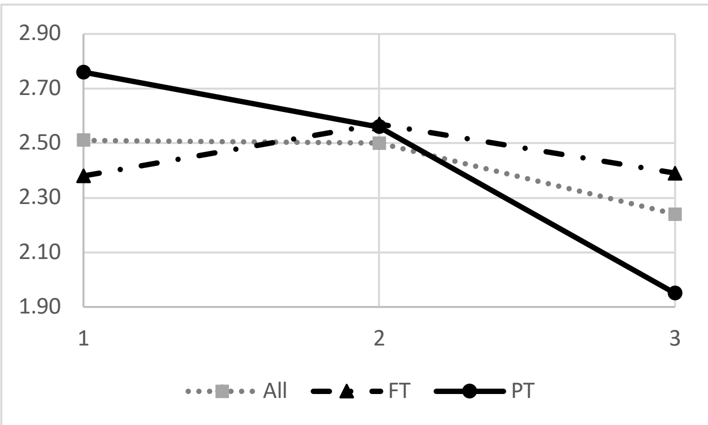

Figure 1: Graphical representation of changes in survey responses to Q3 related to the number of TRIZ heuristics learnt (Likert scale of 5, 1 - Strongly Agree, 5 - Strongly Disagree)

The horizontal axis in Figure 1 differentiates students on the basis of the number of heuristics learnt: 1 – depicts the responses of students early in the course (Pre-TRIZ groups); 2 – the replies of students that studied less than four heuristics (TRIZ-03 groups); 3 – students that learnt all four heuristics (TRIZ-4 groups). The vertical axis shows the Mean values of student responses to Q3 using the Likert scale of 5 (1 - Strongly Agree, 5 - Strongly Disagree).

As shown in Figure 1, there is a tendency for PG students to improve their perception on their problem-solving abilities (Q3) – the more heuristics they learnt, the bigger is the improvement in their opinions on own problem-solving skills. The changes in perceptions of FT students are more complex. It can be seen from Figure 1, the opinions of FT students on their problem-solving abilities worsened. And with more TRIZ heuristics learnt, this deterioration in FT students' perceptions on own problem-solving skills get smaller.

It needs to be noted that although for simplicity purposes Figure 1 depicts only graphical behaviours of student responses to Q3, is clear from Table 1 that the behaviours of their responses to questions Q1, Q2 and Q4 are similar to that of Q3.

Discussion and Conclusion

Statistical analysis of the survey responses of all third-year students that are depicted in Table 1 identifies two contradicting patterns of changes in student perceptions that make it difficult to determine validity of the first hypothesis. On one hand, introduction of four TRIZ heuristics (TRIZ-4 group) statistically significantly improved perceptions of engineering students on two questions related to the idea generation self-efficacy (Q1 and Q2) and on one question associated with the problem-solving self-efficacy (Q3). Although the changes in student responses to Q4 were not statistically significant, the trend for improved perception is visible (change from 2.49/5 to 2.33/5, d=0.22). On the other hand, the responses of students from TRIZ-03 group do not show the trend for improved self-efficacies as a result of learning heuristics. Similarly, it seems that significantly different patterns of change in perceptions of FT and PT students shown in Table 1 and Figure 1 do not support the second hypothesis.

The uncertainty with the validity of both hypotheses can be resolved under condition that FT and PT students were influenced by different factors. As shown in Table 1 and in Figure 1, the influence of TRIZ heuristics on perceptions of PT students fully supports the first hypothesis. The significance and the size of the Pearson correlations for all for questions suggests that learning any number of TRIZ heuristics improved creative problem-solving self-efficacy of PT students. Moreover, learning four heuristics resulted in statistically significant self-efficacy change with large effect (Cohen's d>1).

The change in perceptions of FT students can be explained if it is assumed that they were influenced not only by learning TRIZ heuristics, but also by a shock due to the exposure to 'real engineering problems' for the first time in their lives. The validity of such assumption is supported by (1) vast differences in perceptions of FT and PT students on their creative problem-solving abilities that were recorded by the first survey and (2) by significant difference in work experience of FT and PT students. As shown in Table 1, early in the course, FT students had statistically significantly higher opinions on their creative problem-solving skills than their PT colleagues. Also, the former spent 0.5 years in industry on average and the latter - five years.

PT students spent sufficient time in industry and were not negatively influenced by the challenges of the design projects they had to accomplish. They already faced such challenges many times. As a result, PT students were less positive on their creative problem-solving abilities than FT students. Therefore, the influence of learning TRIZ heuristics on their idea generation and problem-solving self-efficacies was not 'masked' by the influence of design challenges they faced in the course. FT students were influenced by both the project challenges (negatively) and TRIZ heuristics (positively). These two influencing factors could explain why FT students' perceptions on their creative problem-solving abilities went down for those who studied less than four heuristics and stayed practically the same for students that studied all four heuristics. Assuming that FT students were influenced by two factors and

PT students only by TRIZ heuristics, it can be concluded that the data presented in Table 1 support both hypotheses.

This study validates previous findings on the influence of TRIZ heuristics embedded into existing courses on students' creative problem-solving self-efficacy. It also supports the idea of Belski and Belski (2018), who proposed enhancing students' creative problem-solving skills by embedding thinking heuristics into existing engineering courses.

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