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Teaching TRIZ at University: A Longitudinal Study*

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This paper discusses the outcomes of the course on Theory of Inventive Problem Solving (TRIZ unit) delivered at the Royal Melbourne Institute of Technology (RMIT) over the last five years. It analyses the results of numerous surveys on students' problem skills and compares the impact of the TRIZ unit with the impact of a typical engineering unit on students' problem solving abilities. The results presented in this paper suggest that the enrichment approach is superior to the infusion approach for teaching engineering problem solving. The TRIZ unit was also found to enhance students' problem solving self-efficacy significantly more than the four years of an engineering degree. It is concluded, that the most likely reasons for a success of the TRIZ unit can be explained based on the information-processing theories of problem solving: it explicitly teaches tools for problem representation as well as formal problem solving heuristics.

Keywords: Keywords: problem solving skills; TRIZ; self-efficacy

1. Introduction

1.1 Importance of problem solving skills

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 [1]. 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 [2]. Problem solving skills have been included into sets of graduate attributes, such as those, defined by the Australian Technology Network [3]. This 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 [4]. The Australian engineering accrediting body has confirmed this competency "to undertake problem identification, formulation, and solution" as one of the six key engineering abilities [5].

A typical complex engineering problem is open-ended and, at least theoretically, can have many acceptable solutions. These solutions can deploy different principles of operation—mechanical, chemical, electrical, etc. Therefore, to problem solve successfully, engineers are expected to possess extensive knowledge of their discipline and beyond. The importance of discipline-specific knowledge and appropriate cognitive skills to apply the knowledge effectively, present numerous challenges to engineering educators. They need to guide their students to gain extensive scientific, engineering and professional knowledge, and ensure that students become skilled at engineering problem solving in order to apply their knowledge expertly. Problem solving has long been considered as important skill in the engineering profession, therefore the engineering industry has signalled that changes to engineering curricula are long overdue to enable the desired development of students' problem solving skills [6].

1.2 Teaching engineering problem solving: how?

It has been well established that problem solving skills need to be taught explicitly [7]. Two main approaches are normally used to guide such teaching: 'enrichment' and 'infusion'. In the enrichment approach, thinking modules are taught in parallel with existing domain-specific content. Cognitive Acceleration and Instrumental Enrichment programs [8, 9] are examples of this approach in non-engineering areas. The Theory of Inventive Problem Solving (TRIZ) courses [10–12] represent the examples of the enrichment approach in engineering education. Engineering curricula rarely use the enrichment approach in teaching cognitive skills. This is largely because engineering curriculum designers have judged there is insufficient spare space in the already crowded discipline-specific, knowledge-rich curriculum to accommodate special subjects, which focus solely on engineering problem solving skills.

In contrast, infusion strategies embed teaching problem solving in the context of discipline-based curricula [13]. Bruer has shown that infusion across the curriculum is a good strategy for developing 'intelligent' novices [14]. Swartz & Parks as well as Tishman, Perkins, & Jay have also argued for benefits of the infusion approach over the enrichment [15, 16].

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Engineering educators, who usually come from technical backgrounds, are often unaware of the necessity to explicitly teach problem solving methodologies. It is often assumed that students will gain appropriate cognitive skills simply by doing routine course activities and solving progressively 'harder' problems during the four years of an engineering degree. This view is endorsed by anticipated 'transferability' of cognitive skills. Once the skills of engineering problem solving are a subset of cognitive skills (which are generic), they are also considered as transferable [17]. Consequently, these skills can be learnt elsewhere and it does not seem imperative to design engineering curricula explicitly focusing on the development of students' problem solving skills. Thus, engineering curricula are usually developed based on false expectations that the students' skills of problem solving will be enhanced by default, without a properly planned 'infusion' of these skills into the context of discipline-based subjects. Unfortunately the 'transferability' card is not a trump card. Researchers are still uncertain about the degree to which cognitive skills can be transferred. Clanchy and Ballard as well as Gick, for example, pointed out that although generic skills are learned in a discipline context, efficiency of transfer may differ from learner to learner or may not even occur at all [18, 19].

The availability of different modes of teaching (e.g. traditional teaching vs. Problem-Based Learning) and uncertainties on the effectiveness of these teaching strategies [20, 21] complicate the situation for engineering curriculum developers even more. The situation is further entangled by the availability of new educational technologies and computer-based tools.

1.3 Teaching engineering problem solving: what?

A solid review on problem solving strategies found that "*information-processing theories of problem solving emphasize two important processes: (a) generation of a problem representation or problem space (the problem solver's view of the problem); (b) a solution process that involves a search through the problem space*" [19]. Moreover, the problem solving strategies can be either schema-driven or search-based, with the former approach prevailing in experts from semantically rich knowledge domains like engineering [19, 22]. Numerous authors argued the importance of high self-efficacy in achieving project goals [23–25], thus emphasising the significance of elevating problem solving self-efficacy in students. Recent research on engineering problem solving has supported the abovementioned findings affirming that a good problem solver needs to understand the problem well, to deploy good method or strategy and to be motivated and reflective [26, 27].

A recent study on effectiveness of the enrichment approach in teaching engineering problem solving showed that the TRIZ unit conducted over 13 weeks of a semester enhanced the problem solving skills of undergraduate engineering students significantly more than an 'average' discipline units (infusion) [12]. It also demonstrated substantial change in self-evaluation of students' problem solving skills as a result of this 13 weeks TRIZ unit [12]. These results are not surprising. The TRIZ unit incorporated tools for problem representation and formal solution methodologies, which certainly would make a learner more confident in problem solving. However, the study did not investigate whether there were individual discipline-based units which used the infusion strategies and impacted on students' problem solving skills significantly. It also did not answerer the question of whether the cumulative effect of all the discipline-based units that students encounter during four years of engineering degree enhances students' problem solving skills more than the TRIZ unit.

This paper presents the outcomes of teaching TRIZ unit at the Royal Melbourne Institute of Technology (RMIT) over the last five years. It addresses the following research questions: (1) How many individual discipline-based engineering units enhanced problem solving skills of students as much as the TRIZ unit? (2) Do all engineering units students take over four years of an engineering degree collectively enhance students' problem solving skills more than the TRIZ unit alone? (3) How does the TRIZ unit influence students' perceptions of their problem solving skills and why?

2. Data sources

The results presented here originate from three different sources: (i) RMIT Course Experience Surveys, (ii) pre- and post- TRIZ unit surveys, as well as (iii) responses of freshmen and graduating students to the survey questions taken by the students of the problem solving class.

2.1 RMIT course experience survey

RMIT Course Experience Survey (CES) represents the main means of independent evaluation of the units' teaching quality. The CES is usually conducted by the university administration during lecture classes closer to the end of semester (week 10 to week 12). This study gathered the CES data for all engineering units conducted at RMIT between 2006 and 2010. During these five years, thousands of engineering students expressed their opinions on the quality of units taught at RMIT. Over 22,000 CES entries were collected for engineering units taught between 2006 and 2010. Ninety three students enrolled in the TRIZ unit participated in CES surveys over this period.

During the five years, all RMIT CES contained 21 statements relevant to the students' experience in the unit. Five answer options for every statement were offered (Likert-type scale from 1 to 5): 'strongly agree' (identified as '5'), 'agree' (4), 'not sure' (3) 'disagree' (2) and 'strongly disagree' (1). Only one statement of the CES was closely related to engineering problem solving. The statement number six (S6) of the CES was identical in all surveys conducted at RMIT from 2006 to 2010: *"This course contributes to my confidence in tackling unfamiliar problems"*. Although, S6 did not directly ask students to evaluate a unit's impact on their problem solving skills, it was explicitly focused on their improved *confidence in tackling unfamiliar problems*. Thus, the average score achieved by an engineering unit for S6 was considered a reliable indirect measure of impact of this unit on students' problem solving abilities. In order to answer the first research question, the responses to S6 of the students who took the TRIZ unit were compared to the responses of all RMIT engineering units.

2.2 TRIZ unit surveys

To establish what changes to students' problem solving skills occurred as a result of the TRIZ unit, pre- and post-unit surveys were administered to students enrolled in TRIZ units from 2006 to 2010. These two surveys were conducted by the authors in the first and the final weeks of a semester and, over the five years, were completed by 93 students. Both pre- and post-unit surveys consisted of the following six statements:

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*.
Student responses to Q1 and Q6 will be analysed in this paper.

2.3 Surveys of the graduating cohort and the freshmen

To establish the answer to the second research question, surveys of the graduating students and freshmen were conducted. The problem solving skills survey of the graduating cohort was held at the end of semester 2, 2010 (October-November). This survey incorporated all six questions contained in the TRIZ unit surveys presented above. It also included questions focused on the effective ways of teaching problem solving skills. This survey was administered via the web-based SurveyMonkey tool. All graduating engineering student at RMIT were invited to participate. Ninety eight students out of around 300 graduating students from the Schools of Civil and Chemical Engineering (SCECE), Electrical and Computer Engineering (SECE) and Aerospace, Mechanical and Manufacturing Engineering (SAMME) took this survey.

Freshmen, the students, who have just enrolled into the first year of engineering degree in all the abovementioned schools, were surveyed in early semester 1, 2011 (March). This survey was identical to the one taken by the graduating cohort and was also administered via SurveyMonkey. Seventy eight freshmen from the three engineering schools of RMIT participated in this survey.

3. The TRIZ Unit

TRIZ is the Russian acronym for Theory of Inventive Problem Solving. It is a well-established system of tools for problem solving, idea generation, failure analysis and prevention. TRIZ originated in Russia more than 50 years ago [28]. TRIZ thinking tools branch out from the evolution of products and processes, which were revealed through the analysis of thousands of patents. Developed behind the iron curtain, TRIZ was used by Russian engineers and has contributed to many inventions. TRIZ entered the Western world in the early 1990s, and has already helped many Western companies to achieve enormous improvements.

The following is a short description of the tools which were taught to students (see more information on the tools taught in [12]).

3.1 Situation analysis

Situation Analysis (SA) was used by students as the first thinking step on the way to situation improvement. SA deployed in this study required students to answer a set of 11 questions and was designed to question the assumptions of a user and his/her perception of the problem. In a context of the mentioned information-processing theories, SA can be considered as a tool for effective problem representation.

3.2 Method of the ideal result

The Method of the Ideal Result (MIR) has been developed by the author [29]. MIR is based on the TRIZ notion of the Ideal Ultimate Result (IUR). It helps a user with:

- establishing the direction of evolution of a system under improvement and discovering the natural phenomena holding a system's evolution back;

- identifying and utilising the resources which are available, with minimal additional expenses.

All students in the TRIZ unit used MIR by employing the *TRIZ4U MIR Pro-forma*. In the context of human information-processing theory, MIR represents a search-based problem solving heuristic.

3.3 Systematised substance-field analysis

Substance-Field Analysis models any natural and man-made system as a set of interacting elements—a set of substances interacting with each other by means of fields, which are generated by the substances. This tool incorporates both important problem solving processes: problem representation as well as search-based problem solving heuristic.

Students were taught the systematised Substance-Field Analysis procedure, consisting of 5 model solutions [30] which replace the classical 76 Standard Solutions [31]. Most students also used systematised Substance-Field Analysis for idea generation as well as failure prevention.

3.4 40 Innovative principles and the contradiction table

The 40 Innovative Principles are "solution recipes" which have been applied successfully in thousands of patents. To derive the 40 Innovative Principles, more than 20,000 patents were analysed [28]. The 40 Principles can be used separately, but they yield better solutions when used in combination with the Contradiction Table.

Practically, the 40 Innovative Principles is another search-based problem solving strategy. The Contradiction Table, which helps a user to model a technical system under improvement, can be looked at as another tool for problem representation. The *TRIZ4U CT Pro-forma* was utilised by students to model systems accurately.

3.5 Seven steps of systematic thinking

As framework for the four abovementioned TRIZ tools the Seven Steps of Systematic Thinking [32] were used. All students were asked to conduct their practical work by the following steps:

1. Situation analysis.
2. Revealing the system's stage of development.
3. Identifying the ideal solution.
4. Idea generation.
5. Failure prevention.
6. Adjusting the super-system and sub-systems in accordance with the identified solution.
7. Reflection on the solution and the process of the solution.

The student project teams were required to submit formal project reports identifying all seven steps. Reflection on the solution, the process of the solution, problems encountered during the solution process, changes in the thinking pattern, etc. were a compulsory part of the report.

4. Study findings

4.1 TRIZ unit versus an 'average' engineering unit

The TRIZ unit was a standout among all engineering units in regards to the Statement 6 of the CES. Table 1 depicts the comparison of students' responses to S6 of the CES (2006–2010) of TRIZ students (93) with over 22,000 engineering students.

Noting the vast difference in the number of respondents (93 for the TRIZ unit and over 22,000 for all engineering units together), the opinions of students enrolled in all engineering units were considered as representing student's opinion on S6 for the 'average' engineering unit. Under this assumption, the average students' agreements with S6 ('strongly agree' = 5, 'strongly disagree' = 1) for these two units were substantially different: 4.52 for the TRIZ unit and 3.48 for an average engineering unit. A non-parametric Wilcoxon rank-sum test was used to check for a statistically significant difference between TRIZ and the average engineering unit on ratings of S6. The Wilcoxon rank-sum test is a non-parametric equivalent to an independent sample *t*-test. Non-parametric test was used to avoid issues with the assumptions behind the independent sample *t*-test, i.e. normality and homogeneity of variance. The results of the Wilcoxon rank-sum test found that students in the TRIZ course were significantly more likely to rate S6 higher than the average engineering unit, $Z = -9.72$, $p < 0.001$. This statistically significant difference confirms that the TRIZ unit (enrichment) enhanced students' problem solving skills much more than the average engineering unit (infusion). This conclusion is in line with previous findings [12].

Table 1. Comparison of students' responses to the Statement 6 of RMIT CES: *"This course contributes to my confidence in tackling unfamiliar problems"*

Engineering Unit	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
TRIZ (enrichment)	60%	31%	9%	0%	0%
Average (infusion)	16%	40%	25%	14%	5%

4.2 TRIZ unit versus individual engineering units

In order to compare student responses to the CES Statement 6 for the TRIZ unit and for individual discipline units, CES data for one year only was analysed. Comparing individual units over the five years was unfeasible. Over 200 engineering units were offered to undergraduate students every year and it was practically impossible to calculate an average performance for every individual engineering unit over five years. The S6 performances in the TRIZ units conducted from 2006 to 2010 were almost identical. Very similar scores for S6 were achieved in all five years of the study for the 'average' engineering unit. Thus, it was assumed, that analysis of results from any one year alone will provide an evaluation, which is valid for every other year and, therefore, sound for all five years combined. It was decided to look at the engineering units that were taught in a single year of 2009.

Two hundred and twenty three units were offered to undergraduate RMIT engineering students that year. Only 30 of those units achieved the average S6 score equal or above 4 ('agree'). Fifteen of the 30 units were directly devoted to engineering design and were essentially project-based. The remaining 15 represented traditionally run discipline units that incorporated lectures, tutorials and laboratory classes. In other words, only 14% of all the engineering units on offer in 2009 notably contributed to students' confidence in tackling unfamiliar problems. Moreover, only around 7% of traditionally run engineering units, offered to undergraduate engineering students at RMIT in 2009 sufficiently helped them in developing their problem solving skills.

The average students' agreement with S6 for the 223 units offered in 2009 was 3.60 (SD = 0.40). The TRIZ unit that year scored 4.65 (SD = 0.49). The cut-off score for S6 for the top 25% of units across all engineering schools was 3.88. The top scores for S6 for the best non-design unit in each school that year were: 4.16 (SD = 0.97) for SCECE, 4.32 (SD = 0.69) for SAMME and 4.10 (SD = 0.44) for SECE.

These findings demonstrate that (a) very few individual units offered to undergraduate engineering students in 2009 enhanced students' problem solving skills as greatly as the TRIZ unit and (b) even the top performing units in S6 impacted students' problem solving skills much less than the TRIZ unit. Thus, the answer to the first research question (*How many individual discipline-based engineering units enhanced problem solving skills of students as much as the TRIZ unit?*) becomes apparent: very few engineering units offered at RMIT were able to enhance students' problem solving skills on a level compatible to the TRIZ unit.

4.3 TRIZ unit alone versus four years of engineering degree

It has just been confirmed that the impact of the TRIZ unit on students' problem solving skills significantly exceeded the impact of an 'average' engineering unit. Similarly, the TRIZ unit had also outperformed all individual engineering units. To answer the second research question it was required to compare the cumulative effect of all discipline-based units that students encounter during four years of engineering degree at RMIT with the impact of the TRIZ unit [12]. To make a proper judgement on this matter, the data of the pre- and post- TRIZ unit surveys were compared with the surveys administered to freshmen and graduating students. Table 2 pictures the statistics of students' responses to two survey questions Q1: *I am very good at problem solving* and Q6: *I am certain that I am able to resolve any problem I will face*.

It must be noted, that these questions gauge students' perceptions on two distinct aspects of their problem solving ability. Q1 identifies how a student weighs his/her problem solving skills in comparison to the peers—a sort of peer-associated confidence in problem solving. Q6, on the other hand, rates his/her problem solving self-efficacy.

In order to check for statistical differences between the impact of the TRIZ unit and the four years of engineering degree on students' problem solving skills, Wilcoxon rank-sum tests were used. Non-parametric tests were used to avoid issues with the assumptions behind the independent sample *t*-test, i.e. normality and homogeneity of variance. The Wilcoxon rank-sum test checked for statistically significant differences between two distributions of responses to survey questions. The

Table 2. The impacts of TRIZ unit and four years of engineering degree on students' problem solving skills

		Freshmen	TRIZ Before	Graduating	TRIZ After
Q1: I am very good at problem solving	Mean	3.62	3.39	4.06	4.04
	SD	0.87	0.69	0.61	0.56
Q6: I am certain that I am able to resolve any problem I will face	Mean	3.60	2.82	3.41	3.82
	SD	0.96	1.05	0.99	0.82

comparisons consisted of checking for difference between:

a) *Freshmen* and students enrolled in the TRIZ unit in the first week of a semester (shown in Table 2 as *TRIZ Before*);
b) *Graduating* cohort and students enrolled in the TRIZ unit in the last week of a semester (shown in Table 2 as *TRIZ After*);
c) *Freshmen* and *Graduating* students;
d) The TRIZ unit students in the first week of a semester (*TRIZ Before*) and the TRIZ unit students in the last week of a semester (*TRIZ After*).

As there were four comparisons to be made, a Bonferroni adjusted significance level of 0.05/4 = 0.0125 was used to control for inflated type I error. This is an important statistical correction when performing multiple hypothesis tests. The following are the statistical results for all four comparisons of statement Q1, which evaluated student's peer- associated confidence in problem solving:

a) There were no statistically significant differences between *Freshmen* and *TRIZ Before* ($Z = -2.349$, $p = 0.019$). Nonetheless, it seemed that students who chose the TRIZ unit considered themselves as notably poorer problem solvers compared to their freshmen peers.
b) There were no statistically significant differences between *Graduating* and *TRIZ After* ($Z = -0.508$, $p = 0.611$). Both the graduating students and students who took the TRIZ unit exhibited very similar perceptions on their standing in problem solving among their peers.
c) The difference in opinions of *Freshmen* and *Graduating* students were statistically significant ($Z = -3.567$, $p < 0.001$). This finding suggests that the four years of engineering degree did impact on students' opinions of their standing in problem solving among peers.
d) The difference in opinions of *TRIZ Before* and *TRIZ After* was statistically significant ($Z = -6.287$, $p < 0.001$). As in the previous comparison, this revealed a significant impact of the TRIZ unit on students' perceptions of their peer-standing in problem solving.

Basically, the Q1 results did not find significant difference in the impacts of the TRIZ unit and the four years of engineering degree—both improved the perceptions of students on their peer-standing in problem solving significantly and achieved very similar peer-associated confidence levels.

The statistical result for the same four comparisons for statement Q6 unveiled somewhat different pattern on student's problem solving self-efficacy:

a) The differences between *Freshmen* and *TRIZ Before* was statistically significant ($Z = -4.163$, $p < 0.001$). Students enrolled in the TRIZ unit had significantly lower levels of problem solving self-efficacy than freshmen.
b) The difference between *Graduating* students and *TRIZ After* also showed statistical significance ($Z = -2.782$, $p = 0.005$). Although, students who took the TRIZ unit had originally displayed significantly lower level of problem solving self-efficacy than freshmen, after the TRIZ unit, their self-efficacy significantly exceeded the level reached by graduates.
c) There were no statistically significant differences in opinions of *Freshmen* and *Graduating* students ($Z = -1.147$, $p = 0.252$). Unexpectedly, problem solving self-efficacy dropped from 3.60 for freshmen to 3.41 for graduates.
d) The difference in opinions of *TRIZ Before* and *TRIZ After* was statistically significant ($Z = -5.538$, $p < 0.001$). Clearly the TRIZ unit significantly impacted on the students' problem solving self-efficacy.

The Q6 results pinpointed a number of important issues. The comparison a) for Q6 together with the comparison a) for Q1 confirmed that, being an RMIT-wide elective, the TRIZ unit was taken by students with low confidence in their problem solving abilities. The comparisons a) and b) of Q6 found that the TRIZ unit impacted on students' problem solving self-efficacy much more than the four years of engineering degree.

5. Discussion

This study addressed three research questions. Firstly, it aimed to establish *how many individual discipline-based engineering units offered to undergraduate students at RMIT enhanced problem solving skills of students as much as the TRIZ unit?* The TRIZ unit appeared to be a stand out, significantly exceeding the impact on students' problem solving skills by any other engineering units. Moreover, it was discovered, that less than 7% of traditionally taught engineering units enhanced students' problem solving abilities adequately.

It is unlikely that such poor performance of individual engineering units in enhancing students' problem solving skills is specific to RMIT alone. The most recent QS World University Ranking placed RMIT Engineering as the 90th in the world [33]. This high ranking of RMIT Engineering suggests that a mediocre performance of RMIT engineering units in enhancing students' problem solving skills is a norm, rather than an issue unique to RMIT. That is why, more and more engineering programs try new teaching strategies such as problem- and project-based learning [34, 35]. Interestingly, problem-based learning has originally been introduced by medical educators as an alternative to a traditional educational model in order to enhance the problem solving skills of medical students [36]. Once again, poor performance of individual engineering units in enhancing students' problem solving skills pronounces a serious concern regarding the effectiveness of the infusion method. Engineering educators need to find ways to improve the 'infusion' method of developing problem solving skills and to consider teaching problem solving explicitly as suggested by other researchers [7].

Secondly, this study wished to compare the *collective impact of all engineering units taken by students over four years of an engineering degree with the TRIZ unit alone on students' problem solving skills*. It was discovered that the TRIZ unit boosted students' problem solving self-efficacy to the level significantly exceeding the one achieved during four years of a traditional engineering degree. This result has important implications to engineering education. As discussed before, high self-efficacy is essential for success of any human activity [23–25]. For example, Pajares and Miller established the vital importance of self-efficacy on performance in mathematics: "*students' judgments about their capability to solve math problems were more predictive of their ability to solve those problems than were other variables found by previous research also to be strongly related to math performance*" [37]. Similar conclusions on importance of self-efficacy in engineering problem solving have been made by Harlim and Belski, who analysed opinions of engineers on their problem solving abilities [38]. Therefore, engineering degrees are required to notably elevate problem solving self-efficacy of students over the years of study. This research recorded a reduction in problem solving self-efficacy after four years of study and a significant boost of it after the TRIZ unit. The implications of these findings on engineering curricula are apparent. Firstly, individual engineering units must 'infuse' problem solving methodologies more effectively. Secondly, introducing a compulsory unit that explicitly teaches problem solving through 'enrichment' to every engineering degree needs to be seriously considered by engineering educators.

The above-mentioned suggestions for improvement of self-efficacy are made from the data on RMIT engineering programs. Therefore, it would be erroneous to generalise the findings on self-efficacy to all engineering programs. It is likely that some engineering programs are much more successful than RMIT engineering in lifting students' problem solving activity. Nonetheless, there are still many engineering schools that suffer from the same problem as RMIT. After all, RMIT engineering graduates have been sought after by Australian industry for many years and are highly regarded in Asia-Pacific. Moreover, RMIT engineering degrees have been considered as one of the best in the country for many years. This is further evidenced by the above-mentioned QS World University Ranking. The QS employer ranking—rating by major employers on graduates from which universities they would prefer to recruit assessed RMIT Engineering in 2011 as the 51st in the world [33].

The third research question of this study *'How does the TRIZ unit influence students' perceptions of their problem solving skills and why?'* needs additional research. It has been discovered, that the TRIZ unit markedly enhances students' problem solving self-efficacy as well as their peer- associated confidence in problem solving. Most likely, these changes occurred as a result of learning and practicing of two sets of tools: (i) procedures for problem representation and (ii) idea generation heuristics. It is well established that problem analysis and problem representation play important roles in problem solving [19, 22, 38, 39]. Students enrolled in the TRIZ unit applied the procedure of Situation Analysis—a tool for formal problem analysis to two ill-defined problems. They also practiced problem representations of Substance-Field Analysis and of the Contradiction Table. Consequently, students became more capable in analysing engineering problems, so their confidence in problem solving was lifted.

The knowledge of heuristics for generating novel ideas is one of the key components of creativity [40]. Moreover, these heuristics are essential for solution searches when problem schemas are not activated [19]. Most real engineering problems are ill-defined and require engineers to effectively use search-based heuristics [39]. Students of the TRIZ unit acquired skills in three different problem solving heuristics: Substance-Field Analysis, Method of the Ideal Result and 40 Innovative Principles. They also familiarised themselves with the Seven Steps of Systematic Thinking. As a result, students considered themselves capable of approaching ill-defined problems and, therefore, their problem solving self-efficacy was boosted.

6. Conclusions

The results presented in this paper suggest that the enrichment approach is superior to the infusion approach for teaching engineering problem solving.

To develop students' problem solving skills adequately, engineering educators need to not only find ways to improve the 'infusion' of problem solving methodologies into generic units, but also to seriously consider teaching problem solving through 'enrichment'. TRIZ can be successfully used for this purpose—it provides tools for problem representation as well as formal problem solving heuristics.

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