Can Simple Ideation Techniques Enhance Idea Generation?

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Structured Abstract

BACKGROUND
The ability to problem solve effectively is imperative for the engineering profession. It has been reported that current methods of teaching engineering students do not necessarily succeed in enhancing their problem-solving skills (Steiner et al., 2011). It has also been reported that a unit that introduced students to tools of the Theory of Inventive Problem Solving (TRIZ) statistically significantly improved student's problem solving self-efficacy (I. Belski, 2009; I. Belski, Baglin, & Harlim, 2013). Moreover, 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" (I. Belski et al., 2013, p. 322).

PURPOSE
This paper aims to assess whether problem-solving methodologies and ideation heuristics that can be taught in less than two weeks can affect students' problem-solving skills beyond their perception. It evaluates a quantitative influence of two ideation methodologies on student problem-solving performance.

DESIGN/METHOD
Three tutorial groups of the first year students that were enrolled in a unit on Enterprise Engineering participated in this study. All students were given 16 minutes of tutorial time to individually generate as many ideas as possible for the same problem. Students from the Control group were not exposed to any treatment and were simply thinking of the ideas and recording them for 16 minutes. Students from the Random Word group were offered eight random words (a technique suggested by Edward de Bono). Each word was shown to students for two minutes. Students from the Su-Field group were also offered eight sets of words that were presented for just two minutes each. These words, though, were not random. They represented the eight fields of MATCEMIB (Mechanical, Acoustic, Thermal, Chemical, Electric, Magnetic, Intermolecular, Biological) that are an integral part of the TRIZ tool of Substance-Field Analysis (Su-Field) (I. Belski, 2007). Student responses were independently evaluated by four assessors who used the same assessment criteria.

RESULTS
On average, students of the Control group generated just 2 dissimilar solution ideas each. Students from the experimental groups were more productive. The average numbers of the distinct solution ideas proposed by a student from the Random Word group were 3, and from the Su-Field group – 5. The Kruskall-Wallis tests showed that the differences between the numbers of ideas generated by students from the Su-Field group were statistically significantly above the numbers of ideas generated by the other two groups.

CONCLUSIONS
The outcomes of this study show that students who were exposed to the fields of MATCEMIB were much more productive in idea generation than others. It is recommended that the fields of MATCEMIB are introduced to engineering students early during their tertiary education. Moreover, assuming that the basics of Substance-Field Analysis can be taught in a week or two, engineering educators need to consider teaching the complete tool of Substance-Field Analysis to their students.

KEYWORDS
Problem solving, Idea generation, TRIZ, Substance-Field Analysis, MATCEMIB.

Introduction

Importance of engineering problem-solving

The ability to problem solve effectively has been highlighted as one of the imperative requirements of graduate students of the engineering industry (National Academy of Engineering, 2005). This view is endorsed by Engineers Australia, who affirm the ability to problem solve as one of the six key engineering skills (Engineers Australia, 2011). Problems faced by engineers are usually complex and open-ended and require creative solutions. Therefore, Engineers Australia declared that an engineering graduate needs to develop capabilities to problem-solve creatively in order to apply “creative approaches to identify and develop alternative concepts, solutions and procedures, appropriately challenges engineering practices from technical and non-technical viewpoints; identifies new technological opportunities” (p. 6).

Do we succeed in teaching engineering problem-solving?

It has been reported that the traditional methods of teaching engineering students do not necessarily succeed in enhancing their problem-solving skills that are required by the engineering profession (Adams, Kaczmarczyk, Picton, & Demian, 2011; I. Belski et al., 2013; Douglas, Koro-Ljungberg, McNeill, Malcolm, & Therriault, 2012; Woods et al., 1997).

Belski et al., who surveyed 320 undergraduate engineering students from three engineering school of the Royal Melbourne Institute of Technology (RMIT), reported that the problem-solving self-efficacy of the graduates were lower than one of the freshmen (I. Belski et al., 2013). Steiner et al., (2011) who have also analysed the data from the same survey of 320 engineering students, did not find any difference in the problem-solving self-efficacy of students from different schools, who were instructed under different teaching paradigms (242 students were taught traditionally; 78 students experienced rich problem-based learning (PBL) environment). Moreover, the latter study found students’ responses to the survey question “What methods and approaches used by your RMIT teachers improved your engineering problem-solving skills the most?” revealing the need to actively engage engineering students in learning problem-solving methods and creativity heuristics. Forty percent of the surveyed students believed that the most effective means in enhancing their problem-solving skills during study at RMIT were related to acquisition of problem-solving methodologies: 25% of the respondents thought that being guided by a teacher during problem-solving had the biggest effect on their problem-solving skills; 14% praised the problem-solving method that have been taught to them (Steiner et al., 2011, p. 394). Project and Problem Based Learning activities were assessed as the most effective for improvement of problem-solving skills by 20% of students. Individual drills and group work received 6% and 4% of student votes respectively (p. 394).

How to teach engineering problem-solving?

The opinions of students on the importance of teaching them the methods of problem solving and on guiding them in problem-solving activities that have been reported by Steiner et al. (2011) are supported by the results of evaluations of the impact of the McMaster University Problem Solving (MPS) program in Chemical Engineering (Woods et al., 1997), by student opinions who took the PBL module with Lego Mindstorm NXT robots (Adams et al., 2011), as well as by the impact of an unit that introduced students to tools of the Theory of Inventive Problem Solving (TRIZ) (I. Belski et al., 2013).

Adams et al. (2011) surveyed 34 first year engineering undergraduates at the University of Northampton who participated in their PBL module with Lego Mindstorm NXT robots and has reported the problem-solving methods have been assessed by the students at the most useful for development of their problem-solving skills.

MSP incorporated four interlinked compulsory units that were spread over the whole duration of engineering study. These four units taught students how to analyse and model problematic situations, introduced them to effective problem-solving methods and engaged students in extensive problem-solving activities. In order to assess the impact of MPS, the opinions of 202 seniors (who were engaged in MPS) and 238 sophomore engineering students (who had not taken the program yet) on their problem solving confidence was compared. It was found that the MPS program improved the student's confidence statistically significantly ($d = 1.13$; $t=13.18$; $p<0.0005$) (Woods et al., 1997, p. 86).

The TRIZ unit at RMIT was focused onto the abovementioned key means of enhancing problem-solving skills: it taught students four problem-solving heuristics and provided individual guidance in the extensive problem solving activities during a semester. Reporting on the outcome of the TRIZ unit, Belski (2009) compared responses of over 5,600 engineering students who participated in the RMIT Course Experience Surveys (CES) of all engineering units in 2006 with the responses of 34 students who were enrolled in the TRIZ unit on the question "This unit contributes to my confidence in tackling unfamiliar problems". He discovered that student of the TRIZ unit were much more positive in their responses to the question (4.62 versus 3.31, $t = 13.94$, $p < 0.01$, Likert scale of 5, 5 – strongly agree) and concluded that the TRIZ unit improved student's confidence in engineering problem-solving more than an 'average' engineering unit (I. Belski, 2009, p. 106). Later on, Belski et al. (2013) have compared the responses to the same question of over 22,000 engineering students who completed RMIT CES on all engineering units from 2006 to 2010 with the CES responses of 93 students who were enrolled in the TRIZ unit during the same period of time. The results supported the conclusion reached in the previous study. A student who completed the TRIZ unit was on average much more confident in her/his problem-solving abilities than the student who completed an 'average' engineering unit (4.51 versus 3.48, $Z = 9.72$, $p < 0.001$; Likert scale of 5, 5 – strongly agree) (I. Belski et al., 2013, p. 349).

Furthermore, Belski et al. (2013) reported that the TRIZ unit improved student's problem solving self-efficacy more than the units taken cumulatively over the four years of engineering degree at RMIT. To arrive to this conclusion, Belski et al. compared the opinions of the graduating students (96 of the 320 participants of the survey mentioned above) with the opinions of 93 students who completed the TRIZ unit on the question "I am certain that I am able to resolve any problem I will face". The students who completed the TRIZ unit were statistically significantly more confident in their problem-solving ability than the graduates (3.82 versus 3.41, $Z = 2.782$, $p < 0.005$; Likert scale of 5, 5 – strongly agree) (I. Belski et al., 2013, p. 351). It is important to note that the responses of the 93 students who took the TRIZ unit on the same question changed very significantly in just 12 weeks of the semester (before the unit: 2.82, after: 3.82, $Z =-5.538$, $p < 0.001$; Likert scale of 5, 5 – strongly agree).

The abovementioned results strongly support the conclusion reached by Belski et al. (2013) on the importance of teaching problem-solving methods and ideation heuristics to engineering students and on the need for guiding them closely in problem-solving activities. This conclusion, though, was grounded on student perceptions about their problem-solving skills at different stages of their study and on the reported positive correlation of self-efficacy with performance in creative problem-solving (Tierney & Farmer, 2002) and problem-solving in mathematics (Pajares & Miller, 1994). In other words, similarly to Woods et al. (1997), Belski et al. did not assess the actual improvement in problem-solving skills of the students quantitatively, but based their conclusions on qualitative changes in student perceptions on their problem-solving abilities. Therefore, there was a chance that the significantly improved student opinions on their problem-solving skills as a result of the TRIZ unit may have not converted into tangible improvement of their problem-solving skills. Hence, the conclusion that teaching problem-solving heuristics improves problem-solving abilities of engineering students needs further validation.

In order to verify that the positive impact of problem-solving methodologies and ideation heuristics on students' problem-solving skills exists beyond students' perception, it is necessary to evaluate a practical influence of such methodologies on student problem-solving performance. This paper presents the results of the investigation on the actual impact of two simple ideation methods on students' ability to generate solution ideas.

Problem Solving Methodologies and Ideation Heuristics

The problem solving process is usually divided into four to twelve steps (Adams et al., 2011; I. Belski, 2002; Carlson & Bloom, 2005; Polya, 1973; Woods, 2000). These steps can be generalised into the following four main stages: (1) identifying and understanding the problem; (2) planning for solutions and generating solution ideas; (3) implementing a solution; (4) evaluating the solution (Harlim & Belski, 2013). Although, each of the four stages of the problem-solving process is of importance for the development of sound problem-solving skills of engineering students, this study focuses on the second stage – one that can be influenced by the application of ideation heuristics. More specifically, this study attempted to quantify the impact of ideation heuristics on students' ability to generate solution ideas. Student who participated in the study were influenced by two simple heuristics: (i) the Random Word technique (RW), proposed by Edward de Bono (de Bono, 1990) and (ii) the systematised Substance Field Analysis (Su-Field) (I. Belski, 2007).

Random Word (RW)

Edward de Bono, suggested that RW "is the simplest of all creative techniques" (de Bono, 1995, p. 17). The RW technique prescribes a problem solver to use a random word that is not connected to the problem under consideration. De Bono advocated that the RW technique helps a user to generate more ideas, because humans use patterns for problem recognition and problem solving and that

> *the random word provides a new entry point and as we work back from the new entry point, we increase the chances of using patterns we would never have used if we had worked outwards from the subject area (p. 18).*

Random words can be obtained in many ways. Lists of random words that a practitioner can choose from as well as random word generators are freely available on the web. In this study, random words were generated by the authors as suggested by de Bono (1995), by using a dictionary (the Collins Concise Dictionary of the English Language, second edition of 1989 was used). The following are the eight random words that were generated by the authors: Archaism, Right angle, Lotus eater, Emitter, Ozone, Blowhole, Ball-and-socket-joint and Hanky-panky.

Systematised Substance-Field Analysis (Su-Field)

Su-Field is a procedure that systematised the application of the classical TRIZ Substance-Field Analysis with the 76 Standard Solutions (I. Belski, 2007). Su-Field represents technical systems as a set of interconnected components – a set of substances interacting with each other by means of fields, which, in turn, are generated by the substances. Both substances and fields are sketched as circles. Su-Field allows representing different technical systems in a similar way – by means of circle-substances and circle-fields. Such generalisation allows a user to model different systems in a uniform way and to apply similar rules to resolve problems that look dissimilar, but are fundamentally alike. Su-Field consists of 5 Steps and utilises 5 Model Solutions. The 5 Model Solutions represent five general solution "recipes". In order to generate ideas, a practitioner reformulates a general model solution into the problem-specific model solution and then searches through the eight fields of MATCEMIB (Mechanical, Acoustic, Thermal, Chemical, Electric, Magnetic, Intermolecular, Biological) for solution ideas that are 'suggested' by the model solution. It has been reported that Su-Field boosted the number of ideas generated during problem solving and failure analysis (A. Belski, Belski, Chong, & Kwok, 2013; I. Belski & Belski, 2013). Belski and Belski (2013) propounded that the effectiveness of Su-Field stems from its ability to effectively guide a user in a manual search of her/his long term memory data base.

The experiment conducted in this study was limited to exposing students to the eight fields of MATCEMIB. Each field was presented to students together with a simplified list of interactions that illustrated the scope of actions covered by this particular field. Table 1 displays this simplified list of MATCEMIB interactions.

Table 1. Eight fields of MATCEMIB and some field interactions (I. Belski, 2007, p. 17)

Fields	Interactions Including
Mechanical	Gravitation, collisions, friction, direct contact
	Vibration, resonance, shocks, waves
	Gas/Fluid dynamics, wind, compression, vacuum
	Mechanical treatment and processing
	Deformation, mixing, additives, explosion
Acoustic	Sound, ultrasound, infrasound, cavitation
Thermal	Heating, cooling, insulation, thermal expansion
	Phase/state change, endo- exo-thermic reactions
	Fire, burning, heat radiation, convection
Chemical	Reactions, reactants, elements, compounds
	Catalysts, inhibitors, indicators (pH)
	Dissolving, crystallisation, polymerisation
	Odour, taste, change in colour, pH, etc.
Electric	Electrostatic charges, conductors, insulators
	Electric field, electric current
	Superconductivity, electrolysis, piezo-electrics
	Ionisation, electrical discharge, sparks
Magnetic	Magnetic field, forces and particles, induction
	Electromagnetic waves (X-ray, Microwaves, etc.)
	Optics, vision, colour/translucence change, image
Intermolecular	Subatomic (nano) particles, capillary, pores
	Nuclear reactions, radiation, fusion, emission, laser
	Intermolecular interaction, surface effects,evaporation
Biological	Microbes, bacteria, living organisms
	Plants, fungi, cells, enzymes

Methodology

Three tutorial groups of the first year students from the School of Electrical and Computer Engineering (SECE) that were enrolled in a unit on Enterprise Engineering participated in this study. Two groups were influenced by the above-mentioned ideation heuristics; the students from the third group were not influenced in any way – this group represented a Control group. All students were given 16 minutes of tutorial time to individually generate as many ideas as possible for the same problem (to remove the lime build-up in pipes). This problem was suggested by the Engineers Without Borders (EWD) 2014 Challenge as a possible student project, but was not chosen by any student team as a project task.

Initially, the same Power Point slide that contained the problem statement and the photo of the cross-section of a pipe half of which was covered with the lime deposit was presented to the students for two minutes by their tutors. Figure 1 depicts the problem statement slide that was presented to the students from all three groups.

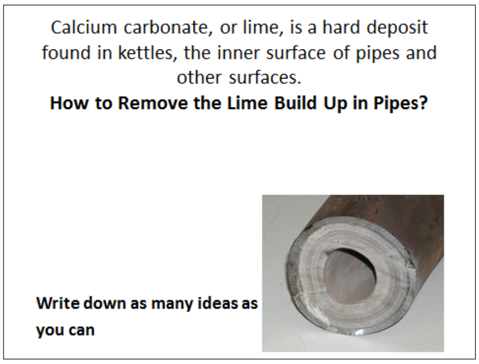

Figure 1. The problem presented to students.

After two minutes of problem introduction that coved only the information presented in Figure 1, all students were asked to work individually and to record as many of their ideas to clean the pipes from lime as possible. The form to record ideas was the same for the students of all three groups. It was distributed to the students just before the problem was presented.

Students from the Control group were not influenced by any ideation methodology. After two minutes of problem introduction, they were allowed to think of the ideas and to record them for 16 minutes. The slide shown in Figure 1 was presented to the students from the Control group for the whole duration of the idea generation session.

After the two minutes of problem presentation, students from the Random Word group were told that during their idea generation session they will be shown some words. No clarifications on what these words are and what to do with them were given. Students were offered the eight random words that were previously mentioned. Each word was shown to them for two minutes. Every two minutes a tutor changed the word on the screen and read the new word aloud. Figure 2 depicts one of the eight Power Point slides that were shown to the students from the Random Word group. Altogether the students from the Random Word group were generating and recording ideas for 16 minutes.

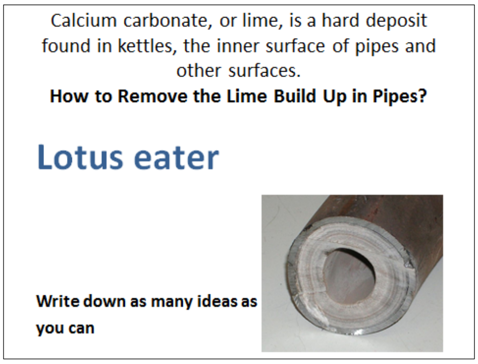

Figure 2. The slide presented to the students from the Random Word group for 2 minutes.

Similarly to the students from the Random Word group, after two minutes of problem presentation, students from the Su-Field group were notified that some words will be shown to them during their idea generation session. No clarifications on what to do with these words were given. Students from the Su-Field group were offered eight sets of words that were also displayed for just two minutes each. These words represented the eight fields of MATCEMIB together with the interactions related to each individual field that are shown in Table 1. It is important to note that when a tutor of the Su-Field group changed slides every two minutes, he read aloud only the name of the field of MATCEMIB that was displayed, but did not read the words that corresponded to the field's interactions that were displayed together with the field's name. Students from the Su-Field group were permitted to generate and to record ideas for the same period of 16 minutes, as students from the other two groups. Figure 3 depicts one of the eight Power Point slides that were shown to the students from the Su-Field group.

Tutors were instructed not to interact with students during idea generation. They only introduced the problem to their students by reading from the slide shown in Figure 1 and announced the words every two minutes to the students of the two experimental groups. Tutors remained silent for the rest of the idea generation session.

Student ideas were independently evaluated by the authors who analysed students' idea-generation forms using the same assessment criteria. These criteria were developed before the experiment and were adjusted after students' idea generation forms were briefly analysed. Among other data, the assessors evaluated the number of independent ideas proposed by each individual student for eliminating the lime build up and collected students' reflections on their activity. Three students were excluded from assessment due to their poor comprehension of English. One student was excluded from the Control group and two from the Random Word group.

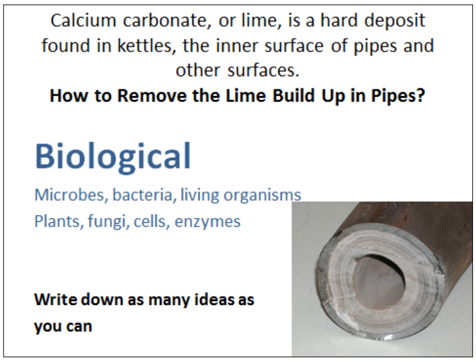

Figure 3. The slide presented to the students from the Su-Field group for 2 minutes.

Results

All four assessors were close in their counts of the number of distinct ideas recorded by individual students. On average a student from the Control group (21 students) recorded just 2 district ideas; one from the Random Word group (17 students) – just over 3; student of the Su-Field group (18 students) – just over 5 distinct ideas. Although the assessments of the number of district ideas recorded by individual students differed slightly between the four assessors, statistical distinctions between the three groups were identical in all four assessments. The differences between the numbers of ideas generated by students from different groups were statistically significant ($p<0.05$, Cohen's $d=0.72$, for Control group vs Random Word group; $p<0.001$, $d=0.89$ for Random Word group vs Su-Field group; $p<0.0001$, $d=1.68$ for Control group vs Su-Field group). The non-parametric Kruskall-Wallis test was used to evaluate the above-mentioned differences in the numbers of distinct ideas generated by students because the Kolmogorov-Smirnov test revealed that the distributions of the ideas generated by students in the Control and the Random Word groups were not normal. The highest number of ideas generated by a student from a particular group was the following: Control group – 5; Random Word group – 7; Su-Field group – 10.

The following are some reflections recorded by the students from different groups. A student from the Control group, who generated 2 distinct ideas, stated that "thinking harder helped to generate more ideas". Another student from the same group assessed her/his work (4 ideas generated) as "I was able to propose many amazing ideas". Three students from the Random Word group, who recorded from 3 to 5 ideas each, reflected that the words shown to them helped them in coming up with new ideas. Four students from the Su-Field group, who generated from 4 to 7 ideas each, commented on the helpfulness of the eight fields of MATCEMIB for generating more ideas.

Discussion

The results of this study support the conclusions of Belski et al. (2013) that problem-solving methods and ideation heuristics can enhance students' problem-solving skills. Students from both Random Word and Su-Field groups generated statistically significantly more ideas than students from the Control group. It is important to note that the students of the two experimental groups were neither taught how to use random words nor how to use the eight fields of MATCEMIB. They were only exposed to the random words and the fields/interactions that were shown for just two minutes each. This exposure to the random words and the fields/interactions helped many students to generate additional solution ideas and to significantly outperform the students from the Control group. Doubtlessly, the impact of teaching students the RW technique and the Substance-Field method on the number of ideas they could come up with whilst solving engineering problems would be more substantial than the impact described in this study.

As every experiment, this study had weaknesses. It compared performances of three different groups of students that were randomly assigned to control and experimental conditions. The conclusions of this study that two simple heuristics significantly improved the outcomes of students' idea generation have been made under assumption that the groups were identical and were representative of the cohort enrolled in engineering degree of SECE. If this assumption on the similarity of the three groups were wrong, the conclusions of this study would be invalid.

The following are the reasons behind the groups' similarity. First of all, all participants of this study were drawn from the population of the first year students of the School of Electrical and Computer Engineering (SECE). These students had identical program, so all of them attended lecture classes together. Thus, students enrolled in different degrees offered by SECE were unlikely to be biased by timetable constraints and were likely to choose tutorial sessions on a random basis. Moreover, all students enrolled into tutorial sessions individually and on the web. Therefore, it is likely that students' choices of the tutorial group to attend did not result in forming tutorial groups that differed significantly in students' prior knowledge and their cognitive skills. Secondly, the Australian Tertiary Admission Rank (ATAR) for the students from the three groups was compared (see http://www.uac.edu.au/ for more information on ATAR). The average ATAR scores of the students from the three groups were very close: 76.6 for the Control group; 78.2 for the Random Word group and 77.3 for the Su-Field group. The fact that the average ATAR scores for the three groups were similar further supports the assumption that the students of all three groups did not differ much in their knowledge levels and their cognitive abilities. Consequently, the assumption of identical composition of all three groups can be maintained and the conclusion drawn that simple problem-solving methods can significantly improve the outcomes of students' idea generation can be considered as valid.

Conclusion

In order to enhance the problem-solving skills of their graduates, the educators from Chemical Engineering at McMaster University have been involved in a significant curriculum redesign. It took them 25 years to implement the MPS program (Woods et al., 1997). The outcomes of this study suggest another approach. In order to enhance students' skills in problem-solving, engineering educators can introduce students to simple problem-solving tools and ideation heuristics and engage them in practicing these tools regularly. Undoubtedly, teaching the ideation tools similar to Random Word and Substance-Field Analysis will require only a few hours of teaching time.

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