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Eight Fields of MATCEMIB Help Students to Generate More Ideas

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Abstract

This paper presents the results of the idea generation experiment that repeats the study originally conducted at RMIT. In order to establish the influence that the experimental treatments make on the number and the breadth of solution ideas proposed by problem solvers with different knowledge levels, students from different years of study were recruited. Ninety students from the Offenburg University of Applied Sciences, Germany were divided into three groups. All students were asked to generate ideas on cleaning lime deposits from the inside of a water pipe and were given 16 minutes to record their individual ideas. Students of two experimental groups were shown some words for two minuted each. The Su-Field group was exposed to the eight fields of MATCEMIB. The Random Word group was shown eight random words every two minutes. The Su-Field group outperformed both the Control group and the Random Word group in the number of ideas generated. It was also found that the students from the Su-Field group proposed significantly broader solutions than the students from the Control and Random Word groups. The overall results of the experiment support the conclusions made by the RMIT researchers that simple ideation techniques can significantly improve idea generation and that the systematised Substance-Field Analysis is a suitable heuristic for engineering students.

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Keywords: Substance-Field Analysis, TRIZ, fields of MATCEMIB, creativity, Random Word, idea generation, problem solving

1. Introduction

Engineers often face ill-defined and knowledge-rich problems that demand novel solutions. For this reason, engineering industry as well as the organisations that accredit engineering degrees request universities to develop engineering graduates that possess advanced skills in creative problem solving and idea generation [1-3]. As reported by many engineering educators, traditional methods of teaching do not necessarily succeed in enhancing students' skills in creative problem solving adequately [4-6]. Therefore, to make graduates more creative, many engineering academics introduce their students to various ideation methods.

A number of researchers have reported on the effectiveness of teaching tools of the Theory of Inventive Problem Solving (TRIZ) to engineering students [4, 7-11]. The authors of the above-mentioned reports either devoted a substantial part of their subject to TRIZ tools or even dedicated the whole subject to teaching TRIZ. Engineering curriculum is tightly packed with the discipline-based material that is constantly expanding. Therefore engineering educators are usually reluctant to replace any of the discipline-specific subjects by a subject that is solely devoted to TRIZ. As a rule, they are prepared to allocate only a short period of their subjects to teaching ideation tools. Accordingly, it is necessary to establish the TRIZ tools that can effectively enhance students' skills in creative problem solving whilst embedded into just a few weeks of subject activities.

The conclusions of the recent study that was carried out at Philips [12] as well as the results of the experiment conducted at the Royal Melbourne Institute of Technology (RMIT) [13] allude to consider the tool of systematised Substance-Field (Su-Field) Analysis as a candidate for embedding into specialised engineering subjects. It seems that Su-Field Analysis, which can be learnt in less than two weeks, can significantly improve the outcomes of idea generation.

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The study at Philips surveyed 13 participants of a project team that was developing solution ideas for a technical problem in an area that was well protected by patents that did not belong to Philips. The team members, who were not introduced to Su-Field Analysis earlier, applied it during a one-day idea generation session. The project team was guided by a Philips employee who learnt Su-Field Analysis by studying the Su-Field Analysis textbook [14]. The team evaluated the influence of Su-Field Analysis on their ability to develop new ideas very highly. The mean value of the team members' response to the statement "*In my view the use of the Su-Field procedure generated ideas that would have been overlooked otherwise*" was 4.11 out of 5 (Likert scale of 5 was used: 5 – strongly agree, 1 – strongly disagree) [12]. The same mean value of 4.11 out of 5 was achieved for the statement "*The Eight Fields of MATCEMIB have helped me to thoroughly search my knowledge for solution ideas on the Project X*".

The study at RMIT engaged three groups of the first year students enrolled in degrees of the School of Electrical and Computer Engineering (SECE). Students were asked to individually record as many ideas as possible for the task of cleaning lime deposits from the inner surface of a water pipe [13]. The Control group of 21 students generated solution ideas for 16 minutes. The two experimental groups were also generating ideas for 16 minutes, but every two minutes the students were shown some words. The Random Word group were shown eight random words (as per the de Bono technique [15]). Students in the second experimental group – the Su-Field group – were shown the names of the eight fields of Su-Field Analysis (MATCEMIB: Mechanical, Acoustic, Thermal, Chemical, Electrical, Magnetic, Intermolecular, Biological) together with the interactions related to each individual field for two minutes per field. The exposure to the eight fields of MATCEMIB assisted the students from the Su-Field group in generating 2.5 times more solution ideas compared to the students from the Control group. The students from the Random Word group generated 1.5 times more ideas when the students from the Control group.

This paper presents the results of repeating the experiment that was conducted at RMIT with the students from the Offenburg University of Applied Sciences, Germany. It engaged students from different years of study in order to establish the influence that the experimental treatments make on a number and the breadth of solutions proposed by problem solvers with different knowledge levels. Also the authors wanted to see whether the exposure to random words and to the eight fields of MATCEMIB will help German students in generating more ideas in a similar way it helped Australian students.

2. Ideation techniques and experimental methodology

2.1. Random Word

Edward de Bono, advocated that Random Word "is the simplest of all creative techniques" [15]. The Random Word technique prescribes a problem solver to choose a random word that may not be related to the problem under consideration. De Bono argued that because humans use patterns for problem recognition and problem solving, the random word is likely to offer a problem solver a new entry point. Starting from this new entry point, a problem solver has higher chances of using thinking patterns she/he would never have used if she/he had worked outwards from the problem's subject area [15]. As a result, a problem solver using the Random Word technique is likely to generate more solution ideas.

Random words can be generated in many ways. The authors of the RMIT experiment used a dictionary for the purpose. The following eight random words were generated by them: Archaism, Right angle, Lotus eater, Emitter, Ozone, Blowhole, Ball-and-socket-joint and Hanky-panky. This study used the same set of random words, but translated into German: Archaismus, rechter Winkel, Lotus-Blute, Strahler, Ozon, Gasblase, Kugelgelenk, Fummelei.

2.2. Systematised Substance-Field (Su-Field) Analysis

Su-Field Analysis is a simple heuristic that systematised the application of the classical TRIZ Substance-Field Analysis with the 76 Standard Solutions [14]. Su-Field Analysis represents technical systems as sets of interconnected components – sets 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 Analysis 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 Analysis 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 for solution ideas that are 'suggested' by the model solution.

Belski and Belski [16] hypothesised that the usefulness of Su-Field Analysis stems from its ability to effectively guide a user in a manual search of her/his long term memory data base. This search is directed by the eight fields of MATCEMIB. The fields act as prompts during idea generation and suggest a problem solver to search her/his knowledge base for solutions that are relevant to a particular field of MATCEMIB.

As it has been advocated in [14], the eight fields of MATCEMIB stand for Natural Phenomena, which have been discovered by science so far. Each of these eight fields is represented by at least one engineering discipline. In essence, the eight fields of MATCEMIB cover the majority of the possible principles of operation that engineers can use in system/product design. Therefore, it is anticipated that when a problem solver during idea generation is prompted by a field of MATCEMIB, she/he is likely to recall the knowledge related to this particular field and, as a result, may propose solution ideas that utilise this specific field.

2.3. Methodology

Three groups of students from the Offenburg University of Applied Sciences, Germany participated in the experiment. The experiment was conducted from late 2014 to early 2015. Thirty seven students from the Control group were in their 3rd semester of the Bachelor of Mechanical Engineering Degree. The Random Word group contained 27 students enrolled into the Master Degree in Mechanical Engineering (8th and 9th study semesters). The Su-Field group consisted of 25 students that were in their 4th semester in the Bachelor of Mechanical Engineering Degree. All the groups were involved in the experiment at the beginning of a scheduled tutorial class. Experiment participation was voluntary. The groups were supervised by the same tutor. The task of cleaning lime deposits was introduced to all groups for two minutes using the same Power Point slide (in German). The slide contained the problem statement and the photo of the cross-section of a pipe half of which was covered with the lime deposit. The English version of this slide is presented in Fig. 1.

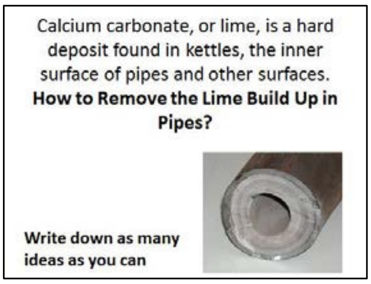

Fig. 1. The Power Point slide presented to all teams.

Similarly to the experiment at RMIT, after two minutes of problem introduction that coved only the information presented in Fig. 1, all students were asked to work individually and to record as many ideas to clean the pipes from lime as possible. The form to record ideas was a German translation of the RMIT form and 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 in silence and to record the ideas for 16 minutes. The slide shown in Fig. 1 was presented to the students from the Control group for the whole duration of the idea generation session.

As the students from the Random Word group that participated in the experiment at RMIT, the students from the Random Word group at the Offenburg University of Applied Sciences 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. Fig. 2 depicts the English version of 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.

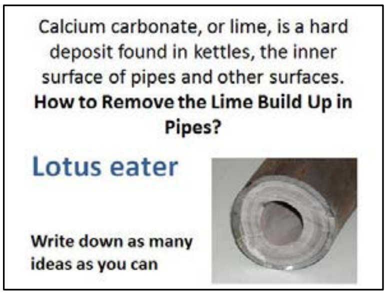

Fig. 2. The slide shown to the Random Word group for 2 minutes.

After two minutes of problem presentation, students from the Su-Field group were also 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.

Table 1. Eight Field of MATCEMIB with interactions

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

Following the experimental arrangements at RMIT, a tutor of the Su-Field group from the Offenburg University of Applied Sciences changed slides every two minutes, but read aloud only the name of the field of MATCEMIB that was displayed. The words that described the field's interactions that were displayed together with the field's name were not read aloud by the tutor.

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. Fig. 3 depicts the English version for one of the eight Power Point slides that were shown to the students from the Su-Field group.

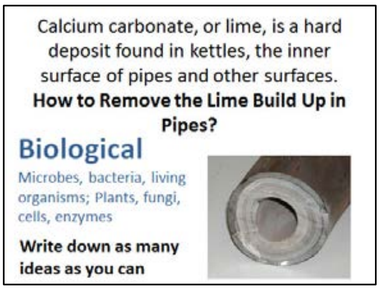

Fig 3. The slide presented to the students from the Su-Field group for 2 minutes.

Students' idea-generation forms were independently evaluated by the two authors. The assessment criteria were identical to the criteria used by the assessors in RMIT study. Among other data, the assessors evaluated the number of independent ideas proposed by each individual student for eliminating the lime build up as well as the distribution of these ideas over the individual fields of MATCEMIB.

3. Results

3.1. The Number of the Proposed Ideas

The inter-rater reliability of assessment by two independent assessors was evaluated using SPSS by establishing the Cronbach's Alpha for the number of independent ideas proposed by each individual student. With the Cronbach's Alpha of 0.925 the assessment was assumed as very reliable. For further analysis the assessment of the number of independent ideas proposed by each individual student made by the two assessors was averaged. Table 2 presents the result of both Australian and German experiments for the number of independent ideas proposed by each individual student (averages of four assessors in Australia and of two assessors in Germany).

Table 2. Independent ideas generated by students from different groups.

Group	Australia			Germany		
Information	Students	Mean	SD	Students	Mean	SD
Control	21 (s1)	2.0	1.4	37 (s3)	3.9	1.7
Random Word	17 (s1)	3.3	1.8	27 (s8,9)	7.7	2.7
Su-Field	18 (s1)	5.1	2.1	26 (s4)	9.5	4.2

The 'Student' columns in Table 2 contain information on the number of students in a group and their study semester. All RMIT students were in their first semester of study. The students from the Offenburg University of Applied Sciences differed in their study years. The students from the Control and Su-Field groups were in their Bachelor years, finishing semesters 3 and 4 respectively. The students from the Random Word group were enrolled in the Master by coursework program and were starting their semesters 8 or 9. The "Mean" and the "SD" columns in Table 2 depict respectively the average number of independent ideas proposed by a student in a particular group and its standard deviation.

The following are the outcomes of the Mann-Whitney Test that was used because the distributions of student responses in both experiments were not normal. The results of the Australian experiment showed statistical significant differences in the number of generated ideas between all three groups. A student from each experimental group have generated statistically significantly more ideas than a student from the Control group (Control versus Random Word: $Z=-2.422$, $p<0.05$; Control versus Su-Field: $Z=-4.123$, $p<0.001$). Also the number of ideas proposed by a student from the Su-Field group was statistically significantly exceeding the number of ideas suggested by a student from the Random Word group: $Z=-2.134$, $p<0.05$.

The results of the experiment conducted in Germany identified statistical significant difference only between the Control group and experimental groups (Control versus Random Word: $Z=-5.066$, $p<0.001$; Control versus Su-Field: $Z=-5.371$, $p<0.001$). Although the average number of ideas generated by a student from the Su-Field group exceeded the number of ideas generated by a student from the Random Word group (9.5 versus 7.7), this difference was not statistically significant.

3.2. The Breadth of the Ideas Proposed

In order to assess the breadth of the ideas proposed by students of each group, every independent idea was assigned to the most appropriate field of MATCEMIB. Fig. 4 and Fig 5 present the distribution of independent ideas for all groups in both Australia and Germany respectively. It is important to note that Fig. 4 and Fig. 5 use data from individual assessors, but not the assessors' average. This explains some discrepancy between the average results presented in Table 2 and the distributions displayed in Figs. 4 and 5.

As shown in Fig.4 and Fig 5, the majority of the ideas proposed by all groups belong to two fields: Mechanical and Chemical. On average, a Control group student from both RMIT and the Offenburg University of Applied Sciences suggested 1.5 ways of cleaning lime mechanically. At the same time, on average, a student from the Control group from Germany proposed nearly twice as many ideas of the chemical removal then the RMIT counterpart (2 versus 1).

The distribution of ideas in Figs. 4 and 5 between the fields of MATCEMIB differs significantly between groups in the breadth of their suggestions. The experimental groups proposed more ideas that were neither mechanical nor chemical in nature then the Control groups.

Interestingly, the Mann-Whitney Test did not show any statistical significance between the breadth of ideas generated by the RMIT students from the Control and Random Word groups. At the same time, statistical significant difference was established between the Control and Su-Field groups at RMIT in all fields excluding Mechanical (Acoustic: Z= -1.960, $p<0.05$; Thermal: Z=-3.772, $p<0.001$; Chemical: Z=-2.609, $p<0.01$; Electric: Z=-3.373, $p<0.001$; Magnetic: Z=-2.251, $p<0.05$; Intermolecular: Z=-2.553, $p<0.05$; Biological: Z=-3.469, $p<0.001$).

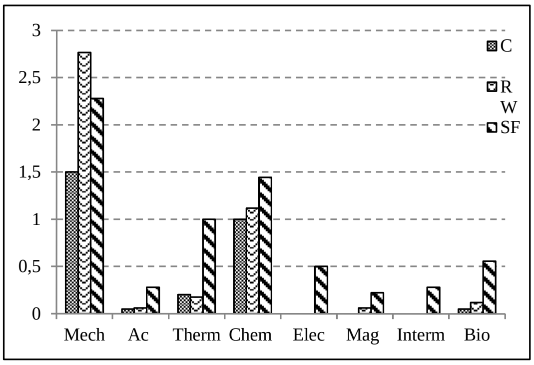

Fig 4. The distribution of student ideas over the eight fields of MATCEMIB: RMIT students, Australia (C – Control, RW – Random Word, SF – Su-Field groups).

The Random Word and the Su-Field groups at RMIT showed statistically significant differences in four fields: Thermal: Z=-3.590, $p<0.001$; Electric: Z=-3.072, $p<0.005$; Intermolecular: Z=-2.313, $p<0.05$; Biological: Z=-2.689, $p<0.01$.

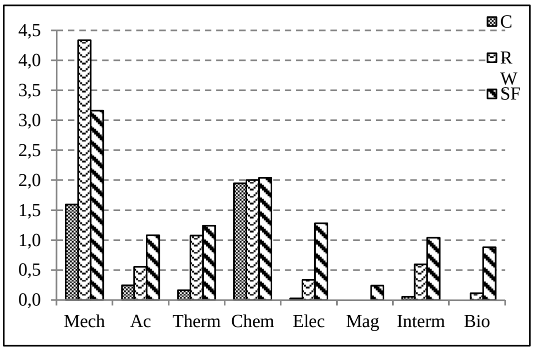

Fig 5. The distribution of student ideas over the eight fields of MATCEMIB: students from the Offenburg University of Applied Sciences, Germany (C – Control, RW – Random Word, SF – Su-Field groups).

Differences in the breadth of ideas between the groups from the Offenburg University of Applied Sciences were somewhat dissimilar to the differences discovered between the groups from RMIT.

The Control and the Random Word groups differed significantly in all fields excluding only Chemical and Magnetic: (Mechanical: Z= -5.601, $p<0.001$; Acoustic: Z= -2.427, $p<0.05$; Thermal: Z=-4.610, $p<0.001$; Electric: Z=-3.044, $p<0.005$; Intermolecular: Z=-3.976, $p<0.001$; Biological: Z=-2.061, $p<0.05$).

Very strong statistical differences existed between the Control and the Su-Field groups in all fields excluding Chemical (Mechanical: Z= -3.686, $p<0.001$; Acoustic: Z= -4.416, $p<0.001$; Thermal: Z=-5.678, $p<0.001$; Electric: Z=-5.739, $p<0.001$; Magnetic: Z=-3.110, $p<0.005$; Intermolecular: Z=-5.231, $p<0.001$; Biological: Z=-5.778, $p<0.001$).

The Random Word and the Su-Field groups showed statistically significant difference in five fields that excluded Thermal, Chemical and Intermolecular (Mechanical: Z= -2.515, $p<0.05$; Acoustic: Z= -2.546, $p<0.05$; Electrical: Z=-3.500, $p<0.001$; Magnetic: Z=-2.680, $p<0.01$; Biological: Z=-4.241, $p<0.001$). It is important to note that the students from the Su-Field group statistically 'outperformed' the students from the Random Word group in ideas related to four fields: Acoustic, Electrical, Magnetic and Biological. Student from the Random Word group were significantly more 'productive' than their Su-Field group counterparts with the ideas of removal of lime deposits mechanically.

4. Discussion and Conclusion

4.1. Variables of Influence

The outcome of idea generation can be influenced by many variables. There are four main variables that could have contributed to dissimilar student performance during both Australian and German experiments. These variables are related to (i) knowledge level, (ii) creativity skills, (iii) student motivation during idea generation and (iv) the influence of the experimental treatment that the groups were under.

The authors of the Australian study appraised the first three variables as not influencing the outcomes of the RMIT experiment. The differences in knowledge levels between the groups were small. All students were in their first year of engineering study. Most of them have recently graduated from the Australian schools with very similar exit scores. The distribution of creativity skills amongst the students from different groups was considered as identical. Australian schools do not offer formal subject on creative thinking, so the probability that one of the groups is significantly different in creative skills from the other groups was negligible. All students in the RMIT experiment followed the same guidance by two tutors who supervised idea generation. Therefore, the authors of the RMIT experiment concluded that the differences in student idea generation resulted solely from the treatments of the experimental groups.

The groups from the Offenburg University of Applied Sciences differed in their knowledge levels and, possibly, had dissimilar levels of creativity skills. Due to the very similar experimental conditions and the same tutor supervising all groups, all students were regarded as having similar motivation during idea generation.

The differences in the knowledge level and the creativity skills of the students from the Control group (semester 3) and the Su-Field group (semester 4) were viewed as insignificant – the latter studied only for one semester longer than the former.

On the other hand, the knowledge base and the creativity skills of the students from the Random Word group could differ significantly to the knowledge/skills of the other two groups. The students from the Random Word group have already completed their Bachelor programs and were in their postgraduate study. Some students from the Random Word group have also spent time with industry. These differences in years of study and practical experience may have resulted in significant enlargement of the knowledge base and in improvement of creativity skills of the students from the Random Word group.

4.2. The Number of the Ideas Proposed

Taking into account the abovementioned differences in knowledge/skills between the RMIT groups and the groups from the Offenburg University of Applied Sciences, the results of the German experiment supported only one conclusion drawn by the Australian experiment. This was related to the significant positive influence of the fields of MATCEMIB on the number of ideas generated by the students. Although the students from the Su-Field group studied for just one semester more than the students from the Control group, the former generated nearly 2.5 more ideas than the latter (9.5 versus 3.9). This difference cannot be explained by additional knowledge/skills that the students from the Su-Field group gained over one additional study semester. If one semester of study were sufficient to influence idea generation that much, the students from the Random Word group would be expected to propose a few times more ideas than the 7.7 they actually generated (it is assumed that the Random Word technique did not impede idea generation). The fact that the students from the Su-Field group that had studied for over two years less than the students from the Random Word group proposed more ideas (9.5 versus 7.7) further supports the conclusion that the fields of MATCEMIB significantly improved the outcomes of idea generation of the students from the Su-Field group.

4.3. The Breadth of the Ideas Proposed

The results presented in Fig. 4 and Fig. 5 reveal the most likely outcome of exposing problem solvers to the eight fields of MATCEMIB. In both Australian and German experiments the students from the Su-Field groups proposed significantly broader ideas of cleaning lime deposits than the students from the Control groups. Statistically significant differences were established in seven fields in the Australian study and in six fields in the German experiment.

Moreover, the ideas proposed by the students from the Su-Field groups utilised more fields than the ideas suggested by the Random Word groups: statistically significant difference in four fields for RMIT students and in five fields for the students from the Offenburg University of Applied Sciences.

The results related to the breadth of the ideas suggested by the students from the Su-Field groups are in line with the expectations of [14, 16] that were mentioned in section 2.2. It is likely that a search for ideas directed by the eight fields of MATCEMIB effectively guides problem solvers in exploration of their long term memory data base.

4.4. Conclusion

The overall results of the experiment conducted at the Offenburg University of Applied Sciences support the conclusions of the RMIT experiment that simple ideation techniques can significantly improve idea generation. The fact that a simple exposure to the eight fields of MATCEMIB brought the improvement in both the breadth and in the number of the ideas proposed by the students supports the effectiveness of the TRIZ tool of systematised Substance-Field Analysis. The authors wish to suggest that engineering educators need to consider embedding simple ideation techniques like Su-Field Analysis into engineering subjects.

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