Engaging engineering students in creative problem solving tasks:
How does it influence future performance?

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INTRODUCTION

Problem solving is a core skill of the engineering profession. Additionally, innovation and creativity are attributes that are often sought by engineering employers [1, 2]. However, several recent studies have highlighted a concerning issue, that the problem solving performance of engineering graduates does not meet the expectations of the engineering industry [1, 3-6].

Numerous researchers have advocated that engineering curricula should include courses that are dedicated to teaching problem solving and creativity, as a way of directly addressing the issue of increasing these skills [7-10]. It has previously been suggested that teaching simple problem solving tools may be a way to overcome this issue, without the need for a significant overhaul of the engineering curricula [11]. One method of enhancing the problem solving and creativity skills of engineering students is to teach creative problem solving skills. Creative problem solving utilises

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both the concepts of creative thinking and critical thinking [12]. Creative thinking is defined as the process of engaging in the search for new and unusual ideas which may be used to solve a problem [12]. Creative problem solving in this study will primarily focus and refer to the creative thinking aspect.

Previous studies have demonstrated that individuals who are exposed to creative problem solving techniques can outperform control groups who have not been provided with any guidance [13, 14]. Studies have also investigated whether engaging individuals in solving a problem with different platforms (computer or pen-and-paper) can lead to different levels of creative performance [13-17]. Currently there is a lack of research which investigates whether engaging engineering students in a creative problem solving task affects long term future performance, and whether the platform which students utilise when learning the creative problem solving technique results in different future performance. It is important that research is undertaken to establish whether teaching students these skills actually leads to improved future performance, and how they be can most effectively delivered. This will enable engineering educators to make an informed decision about the value of teaching such skills.

1 METHODOLOGY

1.1 Design of the study

In order to investigate whether exposing engineering students to creative problem solving techniques may have a measurable influence on long term performance, and whether the approach used to learn the technique influences long term performance, the following two research questions were proposed:

1. How does exposing engineering students' to a creative problem solving technique influence their idea generation performance in the long term?
2. How does the platform an engineering student utilises while learning how to apply a creative problem solving technique, influence their idea generation performance in the long term?

In order to answer the research questions, a series of two related creative problem solving tasks were devised. These tasks (which will be referenced henceforth as Activity 1 and Activity 2) were designed to be carried out several months apart. Activity 1 was designed to engage students in learning how to apply a specified creative problem solving technique, using either a pen-and-paper or computer based approach. Activity 2 was designed as a follow up to Activity 1 so any changes to long term performance, which may be attributed to Activity 1, could be measured. With use of a control group who only participated in Activity 2 but not Activity 1, it would be possible to establish whether participation in Activity 1 had any measureable influence on performance during Activity 2.

1.2 Participants of the study

Participants of the study were third year undergraduate engineering students enrolled in an engineering design unit. Both Activity 1 and Activity 2 took place in tutorial classes allocated to the unit. Activity 1 and Activity 2 were conducted eleven weeks apart, during the same semester. These activities were separate to the rest of the educational material covered in the unit.

Participation in these activities were expected as part of the unit's curriculum, however participation in the research aspect was voluntary. Participants were made aware that they were able to participate in the research aspect by submitting the worksheets (pen-and-paper or computer based) that they had completed during the activities to staff for analysis.

1.3 Description of Activity 1

Prior to Activity 1 commencing, students were allocated into a group that would utilise either a pen-and-paper or computer based approach for the nominated creative problem solving technique. Students who had brought their laptop to the class were provided with the option of which group they would be allocated to. Students who had not brought a laptop to the class were allocated to the pen-and-paper based group. A total of 42 students were allocated to the group which utilised the pen-and-paper based approach, while 32 students were allocated to the group which utilised the computer based approach. For the purposes of conducting the experiment, a paper based and computer based template had previously been created. These templates were designed to be as similar as possible, and followed the steps of the nominated creative problem solving technique. Input text boxes were provided on the web based template, placed in the same location as on the paper based template, for participants to write information.

Participants of Activity 1 were not made aware at any time that a follow up task, Activity 2, would be conducted in the future. This was done to ensure knowledge of the follow up activity would not affect participants' performance or motivation in any way during Activity 1.

Before the experiment began, students were provided instruction in how to apply the creative problem solving technique that would be used during the experiment. The chosen creative problem solving technique was Rule 1 of systematised Substance-Field (Su-Field) Analysis [18]. Su-Field Analysis was chosen for two reasons. First, it is a technique that focuses on finding solutions to technical problems, so it is particularly applicable for engineering students to learn. Secondly, it has previously been shown to be an effective technique for idea generation [11]. The Su-Field Analysis technique utilises the fields of MATCEMIB (Mechanical, Acoustic, Thermal, Chemical, Electric, Magnetic, Intermolecular & Biological) as hints during idea generation. Each field of MATCEMIB is illustrated by a set of "interactions" (e.g. friction, vibration or fluid dynamics for the Mechanical field) which can further assist a person to generate ideas [18]. Training was provided in the form of a 15 minute video which introduced students to Su-Field Analysis, and showed how to apply the technique via a simple example (how to eliminate an annoying fly).

Participants were then presented with a practical problem, shown in *Fig. 1*. Participants were provided with sixteen minutes to individually generate as many solution ideas to the problem as possible. The tutor did not interact with students during this time. Upon completion of the allocated time, participants were able to return the paper based templates with their solution ideas to the tutor or submit their ideas to a web based database.

Fig. 1. Problem presented to participants in Activity 1. Diagram on the left shows application of Su-Field Analysis.

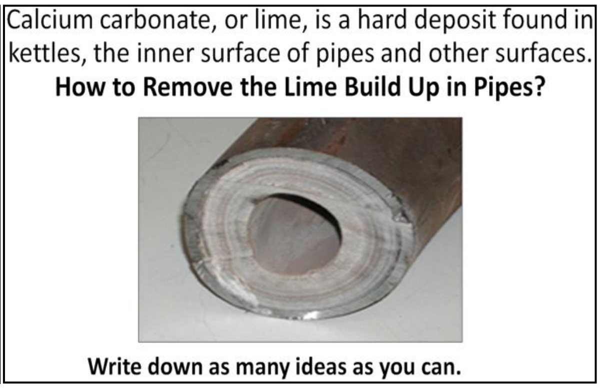

Fig. 2. Problem presented to participants in Activity 2

1.4 Description of Activity 2

Eleven weeks later, during Activity 2, students were provided with a different practical problem, shown in *Fig. 2*. No template or technique were provided or discussed, all participants were only provided with a blank sheet of paper. As in Activity 1, students were provided with sixteen minutes to individually generate as many solution ideas to the problem as possible. Students who participated in Activity 2, but not Activity 1, were used as a control group (N=8). Students who had participated in Activity 1 were allocated into two groups, dependant on the platform they used in Activity 1. There were a total of 16 students who had used pen-and-paper and 17 who had used a computer based approach in Activity 1. These groups enabled establishment of whether learning a creative problem solving technique on either platform leads to improved long term performance, when compared to a control group who had not learnt the technique. It also allowed analysis of whether there were different learning gains as a result of having learnt and first applied the technique via one platform compared to the other.

2 DATA ANALYSIS

The process of creative problem solving focuses on the search for new ideas to resolve a problem. As a result, creative problem solving performance was evaluated based on two established and widely used metrics: idea fluency and idea flexibility [19]. Idea fluency relates to the proficiency which a person can generate ideas (i.e. the number of distinct ideas they generate), while idea flexibility relates to the diversity of the ideas that are proposed [19].

All templates handed back to the tutor or recorded in the database were considered for assessment. Templates were excluded where the participant did not generate any ideas, handwriting was illegible, or clearly did not correctly comprehend the problem.

For each of the two activities, three assessors individually counted and recorded the number of independent ideas generated by each student by evaluating either the handwritten or database recorded responses. This process was used to assess the idea fluency of each participant. The assessors also allocated each potential solution idea to one of the eight fields of MATCEMIB. Upon evaluation, the assessors established that some ideas could clearly not be allocated into one of the field of MATCEMIB, due to the apparent overlap of scientific concepts between fields (Mechanical with Acoustic, and Electric with Magnetic). As a result, the Mechanical and Acoustic fields were combined to form the Mechanical-Acoustic field, while the

Electric and Magnetic fields were combined to form the Electric-Magnetic field. This process lowered the number of available fields from eight to six. The number of fields a participant utilised (i.e. between 1 and 6) was counted and used as the metric to assess the idea flexibility of each student.

The reliability of the three assessors' evaluations was established by assessing the inter-rater reliability. For idea fluency, the Cronbach's Alpha for Activity 1 and Activity 2 were both above 0.9, indicating the reliability of the evaluations. For idea flexibility, the Cronbach's Alpha for Activity 1 and Activity 2 were also both greater than 0.9, meaning the evaluations were reliable. For the requirements of further statistical analysis, the number of ideas and number of fields each participant had utilised were taken to be the average of the three assessors' evaluations. For example, where the three assessors determined a participant generated 4, 3, and 4 ideas respectively, the average of 3.67 ideas was allocated to the student for further analysis.

3 RESULTS

Table 1. Number of Ideas and Number of Fields used by groups in Activity 1 and Activity 2

	Activity 1			**Activity 2**		
Approach used in activity 1	**N**	**Number of Ideas Mean (std. dev.)**	**Number of Fields Mean (std. dev.)**	**N**	**Number of Ideas Mean (std. dev.)**	**Number of Fields Mean (std. dev.)**
Pen-and-paper	42	7.40 (4.46)	3.77 (1.22)	16	4.42 (1.90)	3.13 (0.74)
Computer	32	6.36 (3.48)	3.59 (1.12)	17	4.63 (1.94)	2.78 (0.82)
Control	X	X	X	8	2.58 (1.08)	1.83 (0.59)

Table 1 shows the results of the assessors' evaluations for the number of ideas generated and number of fields used by each group in Activity 1 and Activity 2. The Shapiro-Wilk test was utilised to check whether the number of ideas and number of fields used by each group for both Activity 1 and 2 were normally distributed. Results showed all were not normally distributed. As a result, the non-parametric Mann-Whitney U test was used to check for statistical significance between groups for both metrics.

Results of the Mann-Whitney U test established that there were no statistical differences based upon either the number of ideas generated, or the number of fields used by the two groups from Activity 1.

Because the control group in Activity 2 is relatively small in size, the Cohen's d value was also calculated between groups who participated in Activity 2. This determined the effect size between the control group and groups who had participated in Activity 1, to give further insight into whether there were any apparent learning gains.

For Activity 2, it was established that students who utilised the paper based approach in Activity 1 generated a significantly higher number of ideas ($Z=-2.368$, $p=0.016$, $d=1.14$), and utilised a significantly higher number of fields ($Z=-3.570$, $p<0.001$, $d=1.95$), compared to the control group. Additionally, students who used a computer based approach also generated a significantly higher number of ideas ($Z=-2.745$, $p<0.01$, $d=1.24$), and utilised a significantly higher number of fields ($Z=-2.669$, $p<0.001$, $d=1.31$), compared to the control group. There were no significant differences between the groups which had used pen-and-paper and computer during Activity 1.

4 DISCUSSION

The results presented in Table 1 highlight the performance of groups during Activity 1 and Activity 2. Regarding Activity 1, analysis showed that the average number of ideas generated and number of fields utilised by the pen-and-paper based group was higher than that of the computer based group. However, results showed that the differences for both idea fluency and idea flexibility were not statistically significant, meaning performance can be considered equivalent. These results closely match the findings of a recent study which compared the effectiveness of engaging in idea generation via a paper or computer based approach [20]. This means that in terms of the overall groups, performance during Activity 1 could be eliminated as a factor which may result in different performances during Activity 2.

Results shown in Table 1 clearly show that both groups from Activity 2 who had previously participated in Activity 1, performed considerably more effectively both in terms of idea fluency and idea flexibility, than the control group who had not participated in Activity 1. These differences were all found to be statistically significant and have effect sizes greater than 1.0. In order to have practical significance, it is conventionally considered that an effect size for Cohen's ***d*** should have a value of at least 0.5 [21]. In this case, the values suggest that involvement in Activity 1 had a notable effect on performance during Activity 2. Regarding research question 1, these findings suggest that exposing engineering students to creative problem solving techniques has a clear influence that allows them to solve problems with higher idea fluency and idea flexibility into the long term future.

Comparison of the performance of groups from Activity 2 which had previously participated in Activity 1 revealed mixed results. On average, the number of ideas generated by the group that used a computer approach was higher (4.63 vs. 4.42) than those that used pen-and-paper during Activity 1, but the number of fields that were used were lower (2.78 vs. 3.13). Although there were no significant differences between the two groups for either idea fluency or idea flexibility, the results suggest that students who previously used a computer based approach may show higher idea fluency, but lower idea flexibility in the long term future. Regarding the second research question, these results indicate that using either pen-and-paper or computer based approach to learn creative problem solving techniques, equally enables students to perform more effectively in the long term future. Neither platform can clearly be considered more effective at increasing future performance than the other.

The findings of this study have demonstrated that engineering students were able to generate solution ideas more effectively in the long term, as a result of watching a 15 minute video on a creative technique plus engaging in 16 minutes of idea generation using templates offered by this technique. This suggests that teaching creative problem solving techniques is one method which may positively aid in developing the problem solving and creativity skills of students. In addition, it has been shown that such techniques can be taught via the use of computer or pen-and-paper based approach equally well in a short period of time. The findings have provided some evidence that although students may appear to perform more effectively using a pen-and-paper approach at first (though not statistically significant), the long term results show that it does not matter which platform students use to learn a creative problem solving technique. Learning the technique using either platform is effective.

Computer based platforms have potential benefits over pen-and-paper based approaches which engineering educators may effectively be able to utilise. Computer based platforms can increase the potential reach of learning materials via use of the internet. It also enables learning materials to be disseminated to and engaged with by students without the requirement of class time. In this case, both the training that shows students how to implement a specified creative problem solving technique (such as an instructional video) and templates required to complete the procedure can be web based. Providing students with the opportunity to learn skills such as these may, at least in part, help to increase the problem solving and creativity skills of engineering graduates. This may be one measure which can be adopted to try and help reduce the apparent gap between how important engineering employers consider problem solving skills to be, and how well they rate engineering graduates actually perform using such skills.

There are several limitations of this study which must be noted. The first point is that Activity 1 and Activity 2 were conducted eleven weeks apart. It is possible that participants may have experienced external factors during the 11 weeks between activities which may have influenced student performance in Activity 2. Although the probability of such influence is small, if this occurred in one group but not the other, this may affect results. The anonymous nature of participation in the study meant that participants were not individually identifiable. Therefore, it was not possible to track the individual performance of students between Activity 1 and Activity 2. Only comparison between the overall groups could be made. Additionally, the fact that participants were not randomly allocated to groups, may have affected the results. Furthermore, the size of the control group that may be considered small could have influenced statistical evaluation of the results. Nonetheless, its performance was very similar to performance of the control group that was confronted with a similar task [11], so the influence of the small size does not seem significant. Moreover, three selected metrics (idea fluency, idea flexibility and effect size) were used in conjunction in order to overcome this issue by verifying that performance of other groups was consistently higher across a range of performance indicators.

5 CONCLUSIONS AND FUTURE WORK

The outcomes of this study have shown that engaging engineering students in a less than one-hour activity designed to provide instruction on how to apply a creative problem solving technique, may significantly increase students' capacity to generate creative ideas in the long term. Additionally, it has been demonstrated that the approach (computer or pen-and-paper based) that is used to learn a specified creative problem solving technique does not necessarily affect future performance. As a result, it is viable to conclude that students are able to learn creative problem solving techniques using either pen-and-paper or web based approach. Hence, making use of online based tools designed to teach creativity techniques, is likely to be as educationally effective as face-to-face teaching. Recommendations for future work include introducing computer based tools which can teach creative problem solving techniques to engineering curricula to investigate student perceptions and uptake rates, and the longitudinal benefits or limitations of such tools.

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