Introduction

The Need to Teach Problem Solving Skills

Recent studies of Australian engineering employers suggest that problem solving is a key engineering skill which engineering graduates underperform in (Male, Bush, & Chapman, 2010; Nair, Patil, & Mertova, 2009). In addition, it has been reported that the problem solving confidence of engineering students does not increase over the course of a four year degree, rather it actually decreases (Steiner et al., 2011).

Reason for these issues may be found in the assertion that many universities don't dedicate enough time to courses which develop problem solving and creativity skills (Badran, 2007; Belski, 2015; Charyton, 2014; Daly, Mosyjowski, & Seifert, 2014; Samuel & Jablokow, 2010). Belski et al. attribute this to the fact that engineering curricula designers affirm that there is not enough curricula space for courses dedicated to teaching problem solving skills (Belski, Baglin, & Harlim, 2013).

Problem solving is a process which involves several steps (Belski, 2002). Samuel and Jablokow (2010) assert that engineering students do not carry out idea generation with great success. Lack of instruction means students are likely to fall into the common trap of accepting their first idea as the best solution, and not being open to idea searching (Samuel & Jablokow, 2010). This limits the number of ideas that are able to be considered for development, meaning potentially more appropriate or viable ideas may be missed. It is therefore proposed that the problem solving skills of engineering students may in part be increased through improving their idea generation skills.

How to Teach Problem Solving Skills

One possible method for teaching problem solving skills may be to place the tools and resources needed to learn these methodologies completely online. These tools do not necessarily need to be included in a unit dedicated to teaching problem solving skills. Engineering curricula of tertiary institutions have units dedicated to engineering design and problem solving. If made easily accessible, web based problem solving tools could be introduced to any of these units as a way of actively teaching problem solving and addressing the current issue regarding lack of directed teaching of problem solving skills. Students may repeatedly utilise such web based problem solving tools throughout the course of their studies, continually building upon and enhancing their idea generation skills.

If this is to be made possible, research needs to be done establishing whether problem solving methodologies which are traditionally taught with the pen and paper based approach, can be transitioned to a web based platform without loss of educational quality. Online materials which are based on non-online materials are not automatically equivalent (Lawton et al., 2012; Noyes & Garland, 2008).

Comparison of Web and Paper Based Approaches to Tasks

There is literature comparing the effectiveness of online and traditional approaches to teaching and learning. Significant research has been done comparing the effectiveness of entirely online units comparative to traditional face-to-face units. The focus of this study, however, regards the completion of a singular task rather than an entire unit. Most of the existing literature devoted to comparative evaluation of students' performance whilst completing a single task in two different modes (paper-based and web-based) focus on the completion of an assessment task, rather than the application of problem solving skills. The results of these studies vary in conclusion and provide no clear indication as to which method is more effective (Cagiltay & Ozalp-Yaman, 2013; Campton, 2004; Chua, 2012; Clariana &

Wallace, 2002; Emerson & MacKay, 2011; Jeong, 2014; Macedo-Rouet, Ney, Charles, & Lallich-Boidin, 2009; Macrander, Manansala, Rawson, & Han, 2012; Nikou & Economides, 2013; Seehafer, 2014). These findings are similar to literature reviews conducted by Macedo-Rouet et al. (2009) and Nikou and Economides (2013).

Therefore, these studies cannot reliably be used to infer conclusions on the likely effectiveness of web and paper approaches to problem solving. When completing assessments, students are expected to already comprehend the knowledge they will be tested on and be aware how to apply it. This means that the knowledge they are transferring to the recording medium (paper or web interface) is different to the process of idea generation. The process of idea generation focuses on trying to search the entirety of one's pre-existing knowledge to try and find a potentially good idea.

More related to problem solving, there is existing literature that looks into the benefits or limitations of using computer software for the point of increasing a user's creativity, innovation or problem solving performance (Becattini, Borgianni, Rotini, & Cascini, 2013; Birolini, Rizzi, & Russo, 2013; Cavallucci & Oget, 2013; Hanna, 2012; Michinov, Jamet, Métayer, & Le Hénaff, 2014; Oldham & Da Silva, 2015). The findings of these studies are limited to the apparent improvements in problem solving skills due to the computer based tools, and do not compare how effective the tools are compared to a comparable paper based approach to learning.

From the review covered throughout the preceding paragraphs, it is apparent that there is little pre-existing research which specifically compares the effectiveness of web and paper based approaches to problem solving. Additionally, if it is established that engineering students utilise electronic based materials more than paper based materials, it would suggest there is real potential for students to engage with web based tools, making them effective for teaching problem solving skills. This study aims to address these research gaps by providing insight into the potential use of web based tools for teaching idea generation to engineering students.

Research Questions

1. Do engineering students prefer to utilise electronic or paper based materials while studying?
2. Are engineering students more effective at idea generation using a pen and paper or web based approach?

What is Su-Field Analysis and Why Utilise It

Substance-Field (Su-Field) Analysis is a problem solving methodology which is a part of the Theory of Inventive Problem Solving (TRIZ). Su-Field Analysis gives a problem solver a systematic way to search a wide range of areas of knowledge during the idea generation process (Belski & Belski, 2008). The Su-Field Analysis methodology makes use of the fields of MATCEMIB (Mechanical, Acoustic, Thermal, Chemical, Electric, Magnetic, Intermolecular, Biological) and their interactions (Belski, 2007). Field interactions provided within each field of MATCEMIB (e.g. 'Friction' within the field of Mechanical) act as prompts of prior knowledge the practitioner may have, which may help to resolve the problem being faced.

Su-Field Analysis has been successfully used by professional engineers to come up with new novel ideas to real industry problems (Dobrusskin, Belski, & Belski, 2014). A recent study by Belski, Hourani, Valentine, and Belski (2014) examined the impact that the fields of MATCEMIB had on the idea generation capability of engineering students. When compared with the control group which utilised brainstorming, the group which utilised of the fields of MATCEMIB performed substantially more effectively. Moreover, Su-Field Analysis idea generation heuristic can be taught in under an hour, meaning it can be learnt rather quickly.

This study aims to build upon the findings of Belski et al. (2014) by investigating whether Su-Field Analysis can be successfully transitioned to a web based environment. This will be done by conducting an experiment which compares the effectiveness of Su-Field Analysis for idea generation when carried out on web-based and paper-based interfaces that are comparably similar in terms of content and layout.

Methodology

Participants of the Study

Participants of the study were 90 engineering students from the School of Electrical and Computer Engineering, who were enrolled in the unit Engineering Design 1 during Semester 2, 2014. The experiment was an addition to the unit curriculum for the semester. Participation in the study was voluntary, and the study received ethics approval.

Sixty nine participants of the study were allocated to one of two groups. The group to which a participant was allocated was determined via convenience sampling method. A week prior to the experiment, students were invited to bring their laptop if they wished to participate in the web based version of the study. Students from any tutorial who brought their own laptop were allocated to the Web Based Group (WBG). Students who did not bring a laptop were allocated to the Paper Based Group (PBG). Forty four students were allocated to the WBG, of which 37 (84.1%) were from Australia and 7 (15.9%) were International. Twenty six students were allocated to the PBG, of which 22 (84.6%) were from Australia and 4 (15.4%) were International.

Design of the Experiment

As this experiment builds upon the study carried out by Belski et al. (2014), the design of the experiment was similar. First, in order to make students familiar with the Su-Field Analysis methodology, all participants were given an introduction to the Su-Field Analysis procedure. This introduction was provided in the form of a 15 minute instructional video, which explained Rule 1 of Su-Field Analysis as set out by Belski (2007). A screenshot of the video is depicted in Figure 1. The content of the video incorporated a power point presentation with instructional voice narration and showed the procedure to utilise the methodology. The video introduced the viewer to the fields of MATCEMIB and explained how to model problems and find solutions using the fields of MATCEMIB. A scenario problem (how to get rid of annoying flies) was used to guide the viewer through the entire process. Aside from the instructional video, no other opportunities for practicing the Su-Field Analysis procedure were provided during the experiment prior to the commencement of the idea generation phase. The experiment aimed to establish how well students perform the very first time they try using Su-Field, meaning additional practice was not needed.

Following this video introduction, students from the WBG were directed to the web interface while students from the PBG were provided with the paper-based pro-forma. The first page of both the paper-based pro-forma and the web interface consisted of a pre-experiment questionnaire in the form of two Likert Scale questions. The questions asked were the following: “I always study using electronic materials (computer, e-books etc)” and “I always study using paper/printed materials (textbooks, printed lecture notes etc.)” where 1 is Strongly Disagree and 7 is Strongly Agree. Students were then presented with the problem shown in Figure **2**. A tutor, who facilitated all tutorial classes clarified the Su-Field Analysis methodology and answered questions related to the problem. All students then spent 16 minutes to independently produce as many solution ideas to the problem as possible. The tutor did not interact with the students during this time.

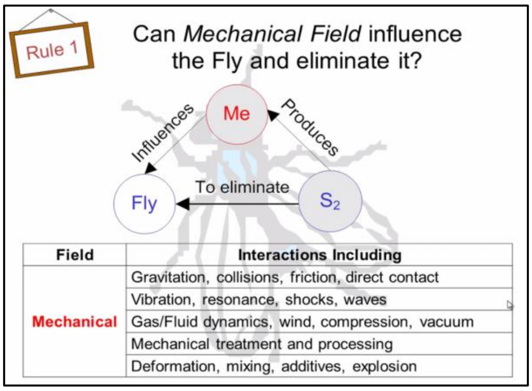


Figure 1: Screenshot of instructional video

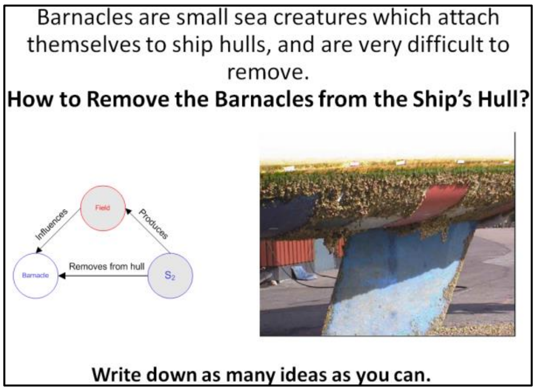
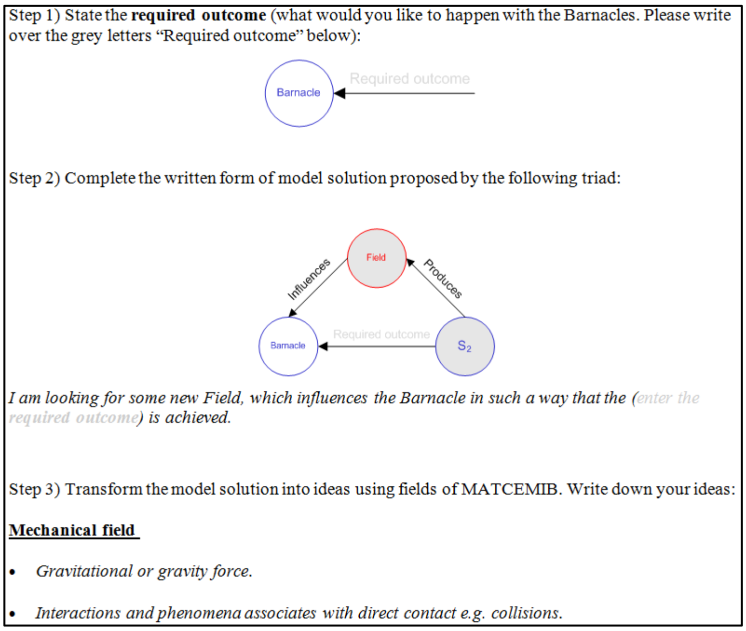


Figure 2: The problem that was presented

Design of the Paper Pro-forma and Web Interface

In the pro-forma provided to students of the PBG (see Figure 3), the fields of MATCEMIB and their interactions were presented in the form of separated dot points. There was ample space underneath each dot point for students to be able to note down their ideas which may be relevant (though ideas could be written anywhere).


Step 1) State the **required outcome** (what would you like to happen with the Barnacles. Please write over the grey letters "Required outcome" below):

Step 2) Complete the written form of model solution proposed by the following triad:

I am looking for some new Field, which influences the Barnacle in such a way that the (enter the required outcome) is achieved.

Step 3) Transform the model solution into ideas using fields of MATCEMIB. Write down your ideas:

Mechanical field

- *Gravitational or gravity force.*
- *Interactions and phenomena associates with direct contact e.g. collisions.*

Figure 3: A segment of the Paper Based Pro-forma provided to the PBG

Figure 4 shows the interface of the web tool which was used for generating ideas. The layout of the dot points (the field interactions) for each field was similar to that on the paper based version (see Figure 3). Text boxes were positioned under each dot point prompt where the user can write their ideas. The web tool was designed so that only one field of MATCEMIB could be viewed at a time. Users could switch between fields of MATCEMIB at any time by pressing the buttons containing the field names. The field names that did not contain any idea entries were highlighted red. When users moved between fields using the buttons, all content currently entered into all the textboxes was automatically saved.

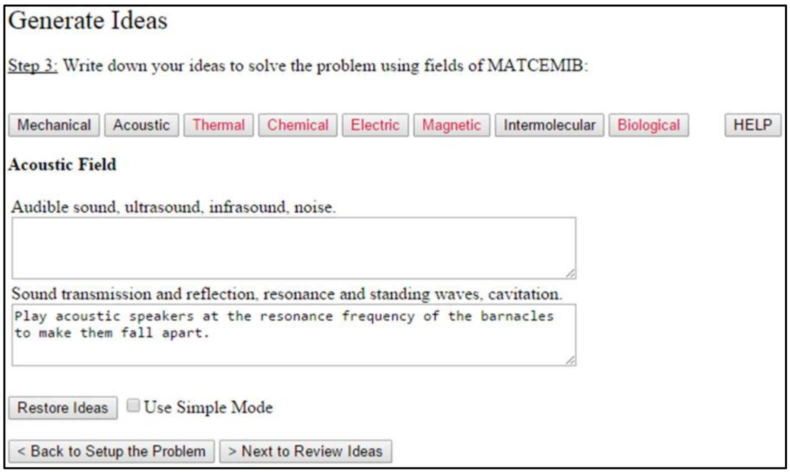


Figure 4: Screenshot of the Web-based Tool used by the WBG

Figure 3 also shows the steps of Su-Field Analysis used for setting up the problem (Steps 1 and 2). On the web interface, these steps were presented on the web page which preceded the idea generation web page. All ideas could be reviewed in list format on the webpage shown subsequently to the idea generation webpage. Students were able to move forwards and backwards between the web pages using buttons at the bottom of the web pages.

Data Analysis Method

All student entries were evaluated according to the same criteria developed prior to the experiment. All student ideas were individually assessed by each of the authors. The total number of ideas generated by each student was determined and recorded. The assessment methodology ultimately relies on interpreting raw data (handwriting or extracted database entries). This suggests the assessment methodology had potential to be subject to individual bias, reasoning why several assessors were necessary. Each individual assessor's evaluations were compared with that of the other individual assessors for consistency.

All pro-forma which were returned to the tutor at the end of each tutorial were considered, as were all entries which were submitted to the database from the web interface. Submitted entries were excluded from analysis where the student has clearly misunderstood the question, or not provided any ideas to solve the problem. Five students were excluded from analysis: two from the WBG and three students from the PBG. The software package for Social Sciences (SPSS) program was used for statistical analysis.

Results

The results of student responses to the questions regarding study behaviour are presented in Table 1. The Wilcoxon Signed Ranks Test was performed to determine whether the difference between means was statistically significant. The results of the test established that there was statistical significance ($Z = -3.045$, $p = 0.002$).

Table 1: Study Behavioural Questions

Question	Likert Scale Result (1- Strongly Disagree, 7 Strongly Agree)	
	Mean (N=90)	Std. Dev. (N=90)
1. I always study using electronic materials (computer, e-books etc).	5.13	1.45
2. I always study using paper/printed materials (textbooks, printed lecture notes etc.).	4.37	1.58

The inter-rater reliability of the evaluations of the three assessors was established by determining the Cronbach's Alpha. The Cronbach's Alpha was determined to be 0.944, meaning the evaluations were reliable. For the purpose of further statistical evaluations, the number of ideas generated by each student was taken as the average of the numbers of ideas counted by the assessors. For example, the assessors may evaluate that a student generated a total of 5, 6 and 6 ideas respectively. The average of 5.67 is therefore taken as the number of ideas the student has generated.

The average number of ideas generated by students of the WBG was determined to be 7.95 (Std. Dev. 4.71) while participants of the PBG generated 10.53 (Std. Dev. 6.81). The highest number of ideas generated by a student from each group was: WBG – 16, PBG – 30. The second highest number of ideas generated in each group was notably lower: WBG – 10, PBG – 21. The distribution of the number of ideas generated by each group was checked for normality using the Shapiro-Wilk method. It was determined that the PBG was not normally distributed ($p < 0.05$), while the WBG was close to the critical value ($p = 0.053$). Accordingly, the non-parametric Mann-Whitney Test method was used to determine the statistical significance between groups. After performing both tests, it was established that the number of ideas generated by students from the WBG and PBG was not statistically significant.

Discussion

Observing the first research question, the results of this experiment imply that engineering students utilise electronic based materials more than paper based materials while studying. Following this outcome, the performance of the two groups was unexpected. Students from the WBG generated fewer ideas on average than students from PBG, although the outcomes were not statistically significant. To answer the second research question, this finding suggests that a web based approach to idea generation may not be as effective as when the idea generation is carried out on paper. This is despite the point that students apparently utilise electronic based material to a greater extent when studying.

Nonetheless, comparison between the groups shows some promising findings in the search for improving the problem solving skills of students. It has been shown that problem solving techniques can be taught completely online via the use of instructional videos accompanied by appropriate web based tools, without appreciable loss of educational quality. It is possible that a web based approach to teaching such methodologies may not be as effective as the face-to-face interaction. In spite of this, it can be argued that it is better that students have access to the web-based tools even if they are not quite as effective as the paper-based, in the overall interest of developing problem solving skills for engineers. This is especially true if it means the material will be covered where it may otherwise by completely omitted due to curricula restraints. Overall, there would still be an improvement in problem solving skills and may be a reasonable compromise for tertiary institutions between educational quality and teaching all the skills students will need in a professional setting.

There are several considerations and limitations of this study which must be noted. It is possible that students may have found the explanation provided by the instructional video unclear. In written feedback provided by students there were no reports that this was the case. Nonetheless, if the web based tool were to be made available to students, additional videos which reinforce the concepts of applying Su-Field Analysis may be useful.

Use of the paper and web based approaches may have some aspects of difference which may contribute to the number of solutions generated. Students using pen and paper are able to sketch concepts whereas those using the web interface cannot, which may impede creative thought processes. Reading on a computer screen also utilises more cognitive workload (Noyes, Garland, & Robbins, 2004), potentially tiring students sooner.

The conclusions of the first research question rely on the perceptions of students, rather than relying on records or observation of study behaviours. Such work was outside the scope of this study. The comparisons made between groups have been based on the assumption that the groups were the same and were representative of the engineering student population. The fact that convenience sampling was used means that the groups were not randomly allocated which may have an effect on the outcome of the results. However, the groups may be considered the same as all participants are first year students and have the same course structure up to this point. The participants of this experiment were from the School of Electrical and Computer Engineering. If students from other engineering disciplines were involved, the outcomes of the experiment may be different. Likewise, the engineering cohort of other tertiary providers may be different, potentially limiting to what extent to findings can be applied to the entire first year Australian engineering student population. The choice of problem solving methodology may also have an impact, others being more or less effective.

The outcomes of this study have provided insight into how web based tools may be used to teach students problem solving skills. There are several directions in which future research may build upon the findings of this study. It needs to be established whether there are cases where a web based approach may be more effective than a paper based approach. There were several variables of the experiment which may have influenced the outcomes, some of which have been discussed (such as experiment environment and student knowledge). One of the important variables not considered was students' problem solving abilities. Analysis of problem solving skills would allow for more accurate evaluation of how similar the groups were. Factors such as variation to the layout of the provided templates may affect how efficiently the Su-Field Analysis procedure can be used on each platform. Additionally, it needs to be established whether students like using these style of web based tools and how likely they would be to make use of them for their own self-improvement. Future research may also look to determine the study habits of engineering students in different year levels to see whether preference for digital based learning changes over time.

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