Can Idea Generation Techniques Impede Effective Ideation?

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CONTEXT Recent research has demonstrated that simple idea generation (ideation) techniques can assist students to generate a significantly higher number of ideas relative to an equivalent control group (Belski et al., 2015), and that students can learn to effectively apply ideation techniques using either a pen-and-paper or computer-based approach (Valentine, Belski, & Hamilton, 2017). This raises the question of how applicable the findings of these studies may be to other ideation techniques in general, and whether certain ideation techniques may actually demonstrate no effective increase in performance, or demonstrate a difference in performance between pen-and-paper or web based approaches. In order to adopt ideation techniques into courses covering creativity or problem-solving, educators should ideally ensure that the techniques in question have been shown to be effective, based upon the outcome of empirical studies.

PURPOSE To establish whether the findings of Belski et al. (2015) and Valentine et al. (2017) may be expanded to incorporate a secondary simple ideation techniques such as Size-Time-Cost Operator, or whether the findings may only be limited to the Fields of MATCEMIB technique.

APPROACH A simple TRIZ (Russian: teoriya resheniya izobretatelskikh zadach, English: theory of inventive problem solving) based ideation heuristic (Size-Time-Cost Operator) was selected for the study, and a pen-and-paper and equivalent computer-based worksheet template designed to guide a person through implementing the technique, were created. Seventy-nine engineering students were allocated into one of three groups; a control group (provided with no external guidance), a group which utilised the pen-and-paper Size-Time-Cost template, or group which utilised the computer-based Size-Time-Cost template. Students were presented with a creativity problem and provided with ten minutes to generate as many ideas as possible. Student performance was then assessed based on the number of distinct ideas and diversity of ideas, and the average performance of each group compared.

RESULTS Results showed that students generated an average of 5.03, 5.04 and 4.20 distinct ideas for the control, pen-and-paper and computer based groups, respectively, and that there were no significant differences between any of the groups for the number of ideas generated, or diversity of ideas. These outcomes do not challenge the findings of Valentine et al. (2017) that students can apply ideation techniques equally effectively using either pen-and-paper or computer, but did not find any difference between control and experimental groups as found by Belski et al. (2014).

CONCLUSIONS The outcomes of this study suggest that certain ideation techniques may not always help a student to perform statistically significantly more effectively, compared to a control group. This reinforces the need for educators to ensure the techniques they aim to introduce are first shown to be empirically effective, and that educators need to emphasise that while heuristics may not always lead to a solution, certain heuristics may be more suitable than others for maximising the chances of the ideation phase being successful.

KEYWORDS Computer-based learning, ideation, TRIZ

Introduction

The ability to be creative and show innovation have been demonstrated to be important for graduates in the field of engineering, with studies reporting that engineering employers place value upon the ability to be able to effectively demonstrate competency in these skills (Male, Bush, & Chapman, 2010; Nair, Patil, & Mertova, 2009). The ability to be creative is primarily concerned with being able to think of novel (i.e. original, non-obvious), useful solutions to resolve a situation (Cropley, 2015), a situation often faced when presented with a new or unfamiliar problem. Creativity therefore relies heavily on the process of idea generation (ideation). Ideation is considered to be a main stage of the problem solving process, according to numerous models which depict the problem solving process (Belski, 2002).

Research has highlighted several concerns within engineering curricula, which can make it difficult for engineering students to effectively demonstrate and enhance their creativity skills. When generating ideas to resolve a new or unfamiliar problem, students will often conceptualise an initial idea and then find it difficult to think of additional ideas (Condoor, Shankar, Brock, Burger, & Jansson, 1992; Kershaw, Holtta-Otto, & Lee, 2011; Samuel & Jablokow, 2010), a phenomenon known as design fixation. Many students become quickly satisfied with the immediate result and move on with the idea they have produced, rather than spending more time searching for other possible solution ideas (Samuel & Jablokow, 2010). Spending only a short time searching for ideas to resolve a problem makes it more likely that ideas which may be more suitable, effective or profitable will be missed during the ideation process. This can severely limit a person’s ability to be creative.

Educators may consider how this challenge may be met, to assist students to overcome these issues and to effectively build their creativity skills. Instead of implementing large scale curricula reforms or designing courses that are dedicated to teaching creativity skills, alternative solutions may be appropriate. One suggestion is that students may be exposed to short (less than an hour duration) creativity related activities throughout the duration of a degree (Belski, Hourani, Valentine, & Belski, 2014). Belski et al. (2014) argue that such activities may be integrated into existing courses such as those on engineering design, and that exposure to such tasks may be an effective method to teach students creativity skills while meeting restrictive curricula restraints. Meta-reviews have previously investigated the effectiveness of creativity training on training participants, and established that creativity training generally results in enhanced creativity levels for involved participants (Scott, Leritz, & Mumford, 2004; Tsai, 2013), suggesting this idea may have credence.

Over a series of replicated experiments, it was consistently shown that introducing students to a simple ideation technique enabled them to perform more effectively when faced with an unfamiliar problem, than a comparable control group (Belski et al., 2015). Moreover, it was demonstrated that exposing students to ideation techniques which do not take much time to learn, can have measurable long term benefits to creativity performance even after an intermittent period of several months (Valentine, Belski, & Hamilton, 2016). These outcomes were expanded upon by Valentine et al. (2017), who demonstrated that students are able to apply ideation techniques equally effectively using either a pen-and-paper or computer-based approach. This outcome lead to the suggestion that self-contained web-based tools may provide a suitable means to enable students to engage in learning ideation techniques, and that this may also be done without requiring educators to provide class time.

Although the results of these studies are encouraging, there is one major limitation. In the empirical studies conducted (Belski et al., 2015; Valentine et al., 2016, 2017), the ideation techniques used have primarily been limited to the Fields of MATCEMIB (Mechanical, Acoustic, Thermal, Chemical, Electric, Magnetic, Intermolecular, Biological) technique, and Substance-Field Analysis technique, which is heavily based upon the Fields of MATCEMIB technique (Belski, 2007). This raises the question to what extent the findings of these studies may be expanded to incorporate additional ideation techniques, or whether the findings may only be limited to the Fields of MATCEMIB. In particular, it was of interest to know whether an alternative simple ideation technique can lead to improved performance over a control group, and whether students may also effectively implement alternative simple ideation techniques using a computer-based or pen-and-paper approach.

Methodology

Size-Time-Cost Operator

To establish whether the findings of Belski et al. (2015) and (Valentine et al., 2017) may be expanded to include a secondary heuristic, selection of an alternative ideation technique was required for this study. Size-Time-Cost Operator is a TRIZ (Russian: teoriya resheniya izobretatelskikh zadach, English: theory of inventive problem solving) heuristic that is used for framing and re-framing problems. The heuristic encourages a practitioner to consider the situation of interest from six alternative new scenarios, and what they may do to resolve the problem under these new conditions. These conditions include scenarios where the practitioner (i,ii) may use or make something very large or very small in size, (iii, iv) has infinite or zero time to resolve the problem, (v,vi) has infinite or zero money to resolve the problem (Gadd, 2011, p. 18). The aim is that the practitioner will be forced to consider new situations, hopefully generating new solution ideas that may be used to aid in resolving the original problem. Size-Time-Cost Operator was selected as the ideation technique for this study, because it does not require specialised domain knowledge to utilise, and is suitable for students to learn in a short period of time (Belski, 2015).

Participants of the Study

Participants of the study were three tutorial classes of third year undergraduate engineering students. The tutorial classes were part of a course on engineering design. The experiment was conducted during a class which included discussion on the topic of creativity and problem-solving within the engineering discipline. As part of the class, students were involved in an ideation activity, which formed the basis for the experiment. This activity was not assessed as part of the course marks, but it was expected that students would attempt the activity as part of the practical material that was covered during the class. Before the activity began, students were made aware of the research project and advised that if they wished to participate, they would be able to anonymously submit their worksheets to the tutor (or online database for computer-based students) for analysis at the conclusion of the task. Participants of one tutorial class were used as a Control Group (CG) (N=23), while participants of the other two classes were allocated to either the pen-and-paper (PPG) (N=26) or the computer-based group (CBG) (N=30), depending on whether they had brought a computer to the class. A pre-experiment questionnaire, shown in Table 1, was utilised to establish whether the groups were equivalent, to allow for comparison between the groups.

Pre-Experiment Questionnaire

All participants were requested to complete a pre-experiment questionnaire. The questionnaire was comprised of questions that were utilised to understand whether the three groups possessed confidence levels similar baseline competencies in computing, problem-solving, and creativity skills, which may influence the outcomes of the experiment. Students were asked questions about their confidence in their computing ability, general problem-solving skill, problem-solving self-efficacy, fluency (i.e. number of ideas) during creative tasks, and regularity of creative thought using a 7-point Likert Scale questions (1-Strongly Disagree, 7-Strongly Agree). Results of the questionnaire may be observed in Table 1. Results of the Mann-Whitney U Test of significance showed that there were no statistical differences between any of the groups on any of the questions, suggesting the groups may be considered equivalent.

Table 1: Pre-Experiment Questionnaire. 7-point Likert (1-Strongly Disagree, 7-Strongly Agree)

Question	CG (N=23) M (SD)	PPG (N=26) M (SD)	CBG (N=30) M (SD)
1. I am very comfortable using computers for university related learning activities.	6.17 (1.20)	6.16 (1.11)	6.67 (0.76)
2. I am very good a problem solving.	4.96 (0.88)	5.24 (0.88)	5.37 (1.05)
3. I am certain that I am able to resolve any problem I will face.	4.78 (1.38)	5.04 (1.14)	5.20 (1.10)
4. I come up with novel ideas all the time.	4.56 (1.50)	4.68 (1.15)	4.77 (1.30)
5. I always have many concepts for how to resolve a problem I am facing.	5.00 (1.60)	5.04 (1.06)	5.07 (1.02)

Worksheet Templates

In order to compare performance of the three groups in an ideation activity and record questionnaire data, it was required that worksheet templates be provided for the participants of each group. Worksheet templates consisted of two sheets of paper in the case of CG and PPG, or two consecutive website pages for CBG. The first page of each template consisted of the pre-experiment questionnaire, and the second page included instructions and space to write during the ideation activity. The paper–based and computer-based templates for PPG and CBG were designed to be as similar as possible, so that any potential difference in performance between the groups may be attributed to the different platforms being utilised. The computer-based template for CBG allowed users to move between sequential web pages using buttons at the bottom of the pages. A button placed at the bottom of the second webpage allowed CBG to submit their ideas to an online database for later analysis. The second page of the worksheet template for CG was a blank and did not provide or suggest any guidance as to what may be done during the ideation activity.

The worksheet templates for PPG and CBG were required to be designed so that participants of these groups could implement the Size-Time-Cost Operator heuristic, without the need for prior instruction. This was done to match the conditions in the experiments by (Belski et al., 2015), where students were not provided with any prior instruction in how to utilise the provided material. The second page of the worksheet templates for PPG and CBG consisted of a set of six short sentences which encapsulate the six scenarios that form the basis of Size-Time-Cost Operator technique. A primary instruction was written at the top of the page: “Consider how you may resolve this problem if you could:”. This was followed by the following six conditions, each placed on a new line; (i) use (or make) something big, (ii) use (or make) something small, (iii) take a very long time, (iv) take only a very short time, (v) spend a very large amount of money, (vi) spend only a very small amount of money.

Experiment Procedure

The design of the experiment was based upon the experiment designs utilised in the studies by Belski et al. (2015) and Valentine et al. (2017), with some changes. Students were first provided with a brief overview of the activity. It was explained that participants would be provided with a worksheet for the activity, shown a creativity related problem, and be provided with 10 minutes to write down as many ideas to resolve the problem as they could. Participants of the study were then provided with a worksheet template applicable to the group they were in, and requested to complete the pre-experiment questionnaire.

Participants were then presented with the problem displayed in Figure 1. This scenario was adapted from a problem originally developed for a TRIZ creativity workshop at the University of Oxford (Gadd, 2011, p. 32). The problem presented the situation of a glass of water that has been placed on top of a table. The problem asked a person to think of as many ways as they can for removing the water from the glass, while ensuring not to move either the glass or the table. Students were provided with 10 minutes to generate ideas and write them down on the provided worksheet or webpage. At the tasks' conclusion, 23 and 26 worksheet templates were handed to the tutor from CG and PPG respectively, while a total of 30 entries from CBG were submitted to the database for analysis.

Figure 1: Problem that required students to generate solution ideas

Data Analysis

Submitted student worksheet templates or database entries were evaluated according to similar criteria followed in the study by Belski et al. (2015). Participants' performance was evaluated according to the distinct number of ideas that they had generated (idea fluency), and the diversity of the ideas that they had generated (idea flexibility). Idea fluency and flexibility are two common metrics that are used to assess creative performance (Cropley, 2000). Outlandish or unusual ideas (such as reversing gravity or using lasers) were not excluded, as long as the proposed solution may somehow resolve the presented problem. Ideas were considered distinct when the methods of removing water were not the same, even if they used similar physical concepts. For example, "use a straw" and "use a vacuum/syringe" were not distinct because they each utilise the concept of suction, while "use a vacuum" and "use compressed air to force out the water" were considered distinct as one idea uses suction while the other uses pressure. Analysis by the evaluators showed that overall, ideas proposed by students tended to align with one of 12 distinct concepts. These concepts including (but were not limited to): displacement, suction, pressure or force (e.g. compressed air), chemical change, evaporation or heating, freezing, absorption, electrolysis, cutting a hole in the base of the glass, syphoning, gravity (e.g. such as reversing gravity), and vibrating the water without moving the glass. To assess idea fluency, it is common that a set of categories are provided. Initially, it was expected that ideas would be allocated to the categories of Size, Time or Cost. However, during evaluation it became clear that these categories were not suitable, because it was often not clear which category (if any) students were considering when writing the idea. As categories utilised in the study by Belski et al. (2015) (the eight fields of MATCEMIB) were suitable, these categories were instead adopted for use in this study. This also allowed for a larger number of MATCEMIB categories to be used (8 instead of 3), allowing idea flexibility to more accurately reflect whether a student had generated ideas which utilised several distinct areas of knowledge.

Due to the subjective nature of the evaluation methodology, three assessors independently evaluated the idea fluency and flexibility for each submitted student worksheet template or database entry. To calculate fluency, the number of distinct ideas proposed by the student was established and recorded. Each idea was then allocated into one of the available categories. Once all ideas had been evaluated, the total number of categories used by the participant was established and recorded as the idea fluency. These evaluations were then checked for inter-rater reliability. The evaluations were shown to be reliable, with Cronbach's Alpha of 0.953 for idea fluency and 0.845 for flexibility. For further statistical analysis, each student's idea fluency and flexibility was then set as the average of the three assessor's evaluations (e.g. 5.33 if evaluations were 5, 5, and 6, respectively).

Results

Results showed that students had an average idea fluency of 5.03 (SD: 1.82), 5.04 (SD: 2.33) and 4.20 (SD: 1.96) for CG, PPG and CBG, respectively. Average idea flexibility was 3.10 (SD: 0.93), 2.99 (SD: 0.78) and 2.68 (SD: 0.90) for CG, PPG and CBG, respectively. The non-parametric Mann-Whitney U Test was used to test for statistical significance between groups, as the Shapiro-Wilk test of normality showed several distributions for idea fluency (CG and PPG) and idea flexibility (CG, PPG and CBG) were not normally distributed ($p < 0.05$). Outcomes showed there were no significant differences between any of the groups for either idea fluency or idea flexibility. Effect sizes between CG and PPG were negligible for idea fluency (Cohen's d = 0.00) and flexibility (Cohen's d = 0.13). Small effect sizes of a level to be considered educationally significant (Wolf, 1986), were established between PPG and CBG for idea fluency (Cohen's d = 0.40) and flexibility (Cohen's d = 0.47).

Due to the lack of significance in performance between groups, the groups may be combined to examine whether the metrics of idea fluency and idea flexibility were significantly correlated. Analysis showed a Pearson's correlation coefficient of 0.763, significant at the $p<0.001$ level. This demonstrated that student's ability to generate numerous ideas was linked to their ability to consider several fields of knowledge in the ideation process.

Discussion

The results of this study have demonstrated that exposing students to the Size-Time-Cost Operator heuristic does not necessarily lead to increased ideation performance relative to an equivalent control group. This outcome does not necessarily suggest that Size-Time-Cost Operator is unable to enhance ideation performance, but that it was unable to in this case. Student ideas generally aligned with one of approximately 12 overall distinct ideas, suggesting that there may only be a limited number of possible solutions to the chosen problem, which may influence the ability of Size-Time-Cost Operator to be effective. Results may differ if students were provided with a problem that can be considered more 'real-world'; this is a potential limitation of the study. This outcome suggests that the findings of Belski et al. (2015) are unlikely to be easily generalised to accurately include a large number of simple ideation heuristics, and that heuristics would each need to be individually evaluated in order to comprehend the effectiveness of each heuristic. Where educators seek to implement the teaching of ideation heuristics into curricula, it is important that the chosen ideation heuristics have been empirically demonstrated to enhance ideation performance over a control group, ideally on several independent occasions. The results suggest that students may be unable to effectively implement Size-Time-Cost Operator without prior instruction. Future research may aim to establish whether providing explicit prior instruction in the use of Size-Time-Cost Operator may lead to enhanced performance over a control group.

Considering the performance of PPG and CBG, although the number and diversity of ideas generated by PPG was higher than CBG, there were no statistical significances for either metric. Therefore when considering statistical significance, it has been shown that students were able to utilise a computer-based Size-Time-Cost Operator template at least as well as a pen-and-paper version, even if the technique itself did not enhance performance relative to a control group. These results do not oppose the results found by Valentine et al. (2017), where the group which utilised the pen-and-paper template generated a higher number of ideas than the computer-based group, but the difference was also statistically insignificant. However, it was also established that the effect sizes between PPG and CBG for idea fluency and flexibility were of an educationally significant level (Wolf, 1986). This potentially suggests that there may have been an unclear minor disadvantage to students who utilised a computer-based approach. The entire ideation phase of the experiment was spent on only one web page, so navigation of the website is unlikely to be an issue. Literature reviews comparing the experience of using paper-based and digital-based platforms have highlighted that reading from computer screens typically takes more cognitive effort and takes longer than reading on paper (Leeson, 2006; Millar & Schrier, 2015). However, the instructions provided to students were relatively minimal with only six short prompts provided, suggesting the cause for difference in performance may reside elsewhere.

The results of this study highlight an important point for educators; if computer-based ideation activities are to be provided for students, it is imperative not only to check if students fare equally well using computer as with pen-and-paper. It is important to ensure that the technique, and way it is being delivered, leads to a measured enhancement to performance.

The Fields of MATCEMIB and Size-Time-Cost Operator heuristics work in different ways, meaning the difference in performance between control groups and groups who implement these heuristics may relate to this. Problem-solving as a process is commonly modelled as a series of four steps including: understanding and framing the problem, devising a solution (ideation), implementing a solution, and evaluating and reflecting upon the implemented solution (Belski, 2002). The Fields of MATCEMIB heuristic works by directly providing a person with a set of suggested solution ideas (a Field of MATCEMIB or specific sub-concept). The aim is that each suggested solution idea may work as an analogy that triggers an idea from the person's long term memory, based upon something they may have seen or done in the past. The Fields of MATCEMIB heuristic is primarily associated with the second phase of problem solving; ideation. The Size-Time-Cost Operator works in a different manner, however. It first suggests a person to consider a set of extreme conditions (framing the problem), then think how the problem may be resolved under each of these extreme conditions (ideation), utilising ideas generated under the extreme conditions to try and resolve the original problem. In other words, the Size-Time-Cost Operator incorporates both the first and second stage of problem solving, not just the second stage as is the case with Fields of MATCEMIB. This may result in Size-Time-Cost Operator requiring more time and effort to be able to effectively generate ideas.

Conclusion

Recent research has demonstrated that exposing students to simple ideation heuristics (the Fields of MATCEMIB technique) was able to enhance their ideation performance relative to a control group (Belski et al., 2015), and that students were able to apply ideation heuristics effectively using either pen-and-paper or computer-based approach (Valentine et al., 2017). This study has investigated whether these research findings are repeatable when an alternative ideation heuristic is applied. Outcomes have demonstrated that exposing students to the Size-Time-Cost Operator technique did not lead to improved ideation performance relative to a control group. This contrasts with previous studies which demonstrate that using the Fields of MATCEMIB technique did improve performance. Results of this study also demonstrated that students were able to apply the Size-Time-Cost Operator technique effectively using either pen-and-paper or computer-based approach, aligning with the results of previous studies. The outcomes of this study suggest that not all well-established ideation techniques enhance idea generation performance. Where educators wish to expose students to simple ideation techniques, it is imperative not to assume that exposing students to any well-established ideation technique will always lead to enhanced performance. It is essential that the decision of what techniques are to be provided or taught is given as much consideration as the primary decision to teach ideation techniques in the first place. The decision of what techniques may be taught should ideally be based upon the results of empirical research that demonstrate the technique to be effective, in order to deliver the highest benefit to both the educator and students.

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