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Prior Knowledge and Student Performance in Idea Generation

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SESSION S2: Educating the Edisons of the 21st Century

CONTEXT Engineering graduates are expected to possess sound skills in generating creative ideas to open-ended problems. Belski and Belski (2016) recently compared the performance of undergraduate engineering students from four countries using an identical idea generation experiment and established that students enrolled in engineering degrees from the Royal Melbourne Institute of Technology (RMIT) performed statistically significantly below their international counterparts. Belski and Belski (2016) associated the established lag in performance with lack of knowledge in science that is caused by weak entry prerequisites to enter the majority of engineering programs in Australia. They have also proposed to reconsider entry science requirements in order to ensure that students accepted to engineering degrees in Australia are better prepared for the engineering profession.

PURPOSE This paper presents the outcomes of the same idea generation experiment that this time was conducted at the University of Melbourne (UoM). It was anticipated that prior knowledge in science possessed by students accepted into undergraduate engineering systems degrees at the UoM exceeded that of their RMIT counterparts. If it were the case and the idea generation performance of the UoM students exceeded that of RMIT students, concerns raised by Belski and Belski (2016) would be validated and would require urgent attention by engineering educators.

APPROACH Ninety three students who have just enrolled in engineering systems degrees at the UoM were involved in an identical experiment to that conducted by Belski, Hourani, Valentine, & Belski (2014). Ideas generated by these students were assessed by two independent assessors that used the same evaluation criteria as the earlier study (Belski et al., 2014). In order to make a more accurate judgement of students' science knowledge they were also asked to identify their secondary school choices of the science subjects.

RESULTS The number of independent ideas and the breadth of these ideas generated by students from the University of Melbourne exceeded that generated by RMIT students. Students from the UoM Control group outperformed RMIT counterparts statistically significantly. Their performance was in line with the performance of students from Czech Republic and Russian Federation. Also, idea generation performance of students from the UoM Control group moderately and statistically significantly correlated with the number of science subjects they studied at secondary school. It was found that experimental treatment influenced idea generation more than prior science knowledge.

CONCLUSIONS The findings partly support the conclusion of Belski and Belski (2016). For the Control group students, who were not influenced experimentally, prior science knowledge did matter; thus, the concerns raised by Belski and Belski (2016) stand. As such, it seems wise for Australian engineering educators to reassess the need for more stringent entry science requirements for engineering degrees. Further research is required to establish the influence of science knowledge and experimental treatment on idea generation.

KEYWORDS Prior knowledge, science knowledge, creativity, idea generation, STEM education, engineering education.

Introduction

Engineering graduates are expected to possess sound skills in generating novel designs and innovative solutions to existing problems. It is therefore no surprise that Engineers Australia has identified creativity as one of the important skills for engineering graduates to possess in the 21st century (Engineers Australia, 2011); furthermore, the Department of Employment has included the skills "identify and solve problems" and "create and innovate" amongst 10 Core Skills for Work (Department of Employment, 2016). However, recent statistics on engineering vacancies in Australia, as well as on the numbers of Australian engineering graduates, indicate that many engineering graduates might be unable to get jobs with established companies and may need to think of launching their own businesses (Engineers Australia, 2017; Stewart, 2017). In light of this, a recent Deloitte report mentioned these particular skills as increasingly important for the success of Australian businesses by 2030 (Deloitte, 2017).

Belski and Belski (2016) suggested that Australian engineering graduates might be lagging their counterparts from other countries in their ability to generate novel ideas to open-ended problems. They compared the performance of undergraduate engineering students from four countries in the same idea generation experiment and established that students enrolled in engineering degrees at the Royal Melbourne Institute of Technology (RMIT) performed statistically significantly below their international counterparts in terms of both the number and breadth of ideas generated. Belski and Belski considered the following seven factors that could have contributed to the significantly lower performance of RMIT students: *"(a) differences in prior science knowledge of the student participants, (b) differences in their experiences, (c) dissimilarity in their creativity skills, (d) differences in student motivation during idea generation, (e) differences in experimental conditions, (f) cultural and language differences as well as (g) the influence in the treatment that the experimental groups were under"* (p.2).They concluded that the main reason for such poor performance of RMIT students was due to their insufficient knowledge of science.

In order to appraise the validity of Belski and Belski's conclusion on the critical influence of scientific knowledge on idea generation in engineering, the original idea generation experiment was repeated at the University of Melbourne (UoM). Although both universities had the same minimum requirements for VCE study scores in Mathematical Methods and English, the UoM also required a study score of at least 25 in one of Biology, Chemistry or Physics. Additionally, the Clearly-In ATAR for RMIT was 75, while for UoM it was 85 and so it was expected that students that enter science study at UoM with the intention to complete an "engineering systems" major have better science knowledge than those that enrol in an engineering degree at RMIT. This would then imply that the idea generation performance of students from UoM in the experiment should exceed that of RMIT students and be on the par with that of students from foreign countries (Belski & Belski, 2016). In essence, this study tried to establish whether the following three hypotheses are true:

1. Hypothesis 1: The Control group from UoM will statistically significantly outperform the Control group from RMIT.
2. Hypothesis 2: The MATCEMIB+ from UoM will statistically significantly outperform the MATCEMIB+ group from RMIT.
3. Hypothesis 3: Additional science knowledge helps students to generate more ideas and with greater breadth.

Methodology

Ninety-three students that have just enrolled in the Bachelor of Science degree at the University of Melbourne participated in this study, using the same idea generation experiment that was originally conducted by Belski et al. (Belski et al., 2014). Twenty two percent of the participants graduated from secondary school in Australia; 78% were international school graduates.

Students from four tutorial groups participated in the experiment. Groups were randomly assigned to four conditions: one control and three experimental. All participants were given 16 minutes of tutorial time to individually generate as many ideas as possible for the same open-ended problem (to remove the lime build-up in water pipes). Prior to generating ideas, tutors presented students with the same PowerPoint slide for two minutes. This slide contained the problem statement and a photo of a cross-section of a pipe, half of which was covered with lime deposit. This slide is shown in Figure 1a. After a two-minute introduction to the problem that covered only the information presented in Figure 1a, all students were asked to work individually and to record as many ideas as possible to remove the lime build-up from the pipes. The form to record ideas was distributed to the students just before the problem was presented. The form was the same for the students of all four groups and was the same form that was used in the original experiment but with some extra fields for students to indicate whether they studied physics, chemistry, biology, mathematical methods and specialist mathematics at secondary school.

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

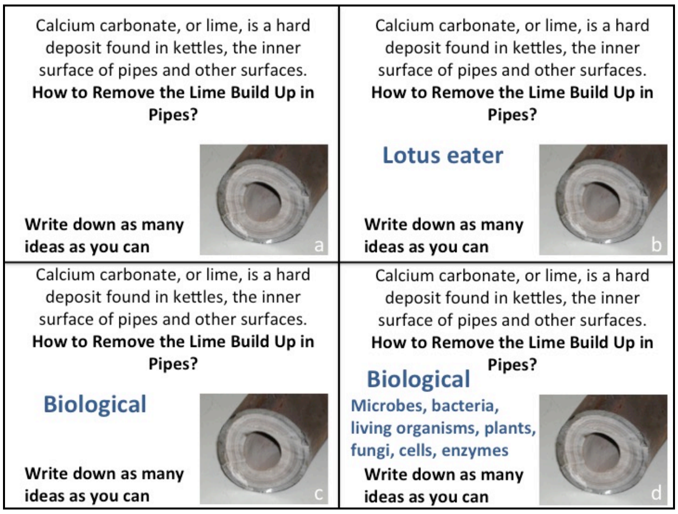

Figure 1: The Power Point slides presented to students: a) task introduction and Control group; b) Random Word group; c) MATCEMIB group; d) MATCEMIB+ group (Belski et al., 2015).

After two minutes of problem presentation, students from the three experimental groups were told that during their idea generation session some additional words will be shown on the PowerPoint slide. No explanation of what these words will be and what to do with them were given. Students from the Random Word groups were offered the eight random words that were used in the original experiment (i.e. Archaism, Right angle, Lotus eater, Emitter, Ozone, Blowhole, Ball-and-socket-joint and Hanky-panky). Students from the MATCEMIB group were shown the names of the eight fields of MATCEMIB (i.e. Mechanical, Acoustic, Thermal, Chemical, Electric, Magnetic, Intermolecular and Biological). The MATCEMIB+ group students were presented with the names of the eight fields (in large font) as well as some words (in small font) that illustrated the interactions of the particular field (e.g. for the Mechanical field - friction, direct contact, collision, wind, etc.) The name of each field as well as each random word was shown to the students from the experimental groups for two minutes. Every two minutes a tutor changed the word on the screen and read the new word aloud. When a tutor of the MATCEMIB+ group changed slides every two minutes, they read aloud only the name of the field of MATCEMIB that was displayed in large font, but did not read the words that illustrated field interactions that were displayed in small font together with the field's name. Altogether the students from all groups were generating and recording ideas for 16 minutes. Figure 1 depicts one of the eight Power Point slides that were shown to students from different groups: Figure 1a – the Control group; Figure 1b – the Random Word group; Figure 1c – the MATCEMIB group; Figure 1d – the MATCEMIB+ group.

Results

General idea generation performance

Two independent assessors evaluated the student idea generation forms, using the same criteria as the assessors in the previous studies. These criteria were developed for the original study (Belski et al., 2014). Among other items, assessors counted the number of distinct (independent) ideas proposed by each student without necessarily assessing their practicality. In order to judge how broad these independent ideas were, each idea was assigned to a field of MATCEMIB that most closely matched the proposed principle of operation. The inter-rater reliability of assessment by the independent assessors was evaluated with SPSS by establishing the Cronbach's Alpha for the number of independent ideas proposed by each individual student. The Cronbach's Alpha exceeded 0.9, which suggested excellent internal consistency of assessment of the two assessors. Accordingly, the assessment of idea generation of students was evaluated as being very reliable. For further analysis, the number of independent ideas proposed by each individual student made by the assessors was averaged.

Table 1 presents the result for the average number of independent ideas proposed by the students in each group (Mean) and the breadth of these ideas (Breadth). It also contains information on the group sizes (N) and a percentage of local students in each group (*%Local*).

Table 1: Number (Mean) and the Breadth of distinct ideas generated by students from UoM

Group Information	UoM		
	N (*%Local*)	Mean	Breadth
Control	27 (*19*)	3.91	2.96
Random Word	25 (*24*)	3.30	2.48
MATCEMIB	18 (*17*)	4.17	3.61
MATCEMIB+	23 (*26*)	5.61	4.48

The breadth of ideas was calculated as a sum of eight terms, each equal to a fraction of students from each group that proposed distinct ideas that were assigned by the assessors to each individual field of MATCEMIB . For example, the following is the spread of the ideas for removing lime build-up proposed by the students from the Control group: 85% of students proposed Mechanical ideas; 7% - Acoustic; 74% - Thermal; 85% - Chemical; 19% - Electric; 7% - Magnetic; 11% - Intermolecular; 7% - Biological. Therefore, the breadth of ideas proposed by the Control group was equal to 2.96:

$$Breadth = 0.85 + 0.07 + 0.14 + 0.74 + 0.85 + 0.19 + 0.07 + 0.11 + 0.07 = 2.96 \quad (1)$$

The distributions of both the number and the breadth of ideas were not normal in some of the groups, therefore an independent samples Kruskal-Wallis test was conducted. It showed a statistically significant difference in both the number and the breadth of ideas between the groups ($p<0.001$). Pairwise comparisons (Dunn-Bonferroni) showed statistically significant difference in breadth ($Z=-3.656$, $p<0.005$) and the number ($Z=-2.708$, $p<0.05$) of ideas between the Control group and the MATCEMIB+ group. Similarly, the students from the MATCEMIB and MATCEMIB+ groups outperformed the peers from the Random Word group (MATCEMIB: breadth: $Z=-2.771$, $p<0.05$; MATCEMIB+: breadth: $Z=-4.814$, $p<0.001$; number:

Z=-4.261, p<0.001). Differences in performance between all other groups were not statistically significant.

Influence of scientific and mathematical knowledge on idea generation

Table 2 shows the percentages of students from the four groups that have studied physics, chemistry, biology, mathematical methods and specialist mathematics at secondary school.

Table 2: Percentages of students that studied science and mathematics at high school

Group	Physics	Chemistry	Biology	Math Meth	Spec Math
Control	100%	67%	41%	81%	70%
Random Word	80%	88%	40%	100%	48%
MATCEMIB	100%	78%	17%	83%	50%
MATCEMIB+	85%	95%	55%	91%	59%

The data presented in Table 2 suggest that science and mathematics knowledge of students from the four groups was likely to be similar and that the majority of participants were reasonably knowledgeable in physics and chemistry.

In order to assess the influence of knowledge of science and mathematics on the outcomes of idea generation, the individual score of science knowledge (SK) and the score of mathematics knowledge (MK) were introduced. Each study area was given a score of one and these scores were summed separately for science and mathematics for each participant. If, for example, a student stated that they studied physics, chemistry and mathematical methods, the science knowledge score was SK=2 and the score of mathematics knowledge MK=1. In the case when a student studied all five subjects at high school, both scores were the highest: SK=3 and MK=2.

Analysis of correlations (Pearson) of the breadth and the number of the ideas proposed by individual students from different groups and their individual knowledge scores in science and mathematics identified that statistically significant correlations (2-tailed, p<0.05) existed only for the students from the Control group and only with their science knowledge score (SK) (breadth: r=0.411; number: r=0.421). Neither the number, nor the breadth of ideas correlated with the score of mathematics knowledge (MK) in any group. The science knowledge score (SK) did not correlate with the breadth and the number of ideas for the students from the experimental groups.

Control and MATCEMIB+ groups: University of Melbourne versus others

Table 3 presents the result for the average number and the breadth of independent ideas proposed by the students from the Control and the MATCEMIB+ groups from RMIT (Australia), BUT (Czech Republic), KNASTU (Russian Federation) that were discussed by Belski and Belski (2016) and by the students from UoM (Australia) that participated in this study. Table 3 retains the original notations of Belski and Belski (2016) that identified statistically significant difference of the number and breadth of ideas generated by students from BUT and KNASTU with the corresponding values of the groups from RMIT. The **normal bold** font identifies statistical significance of p<0.001; the ***italicised bolded*** font a p<0.05. It is important to note that differences in performance between the same groups (Control or MATCEMIB+) from BUT and KNASTU were not statistically significant.

Table 3: Idea generation results of students from UoM compared with students from other universities (Belski & Belski, 2016).

Group Information	RMIT (2014)			BUT (2015)			KNASTU (2015)			UoM (2016)		
	N	Mean	Breadth	N	Mean	Breadth	N	Mean	Breadth	N	Mean	Breadth
Control	21	2.02	2.05	18	**3.56**	***2.53***	21	**4.32**	***2.57***	27	**3.91**	***2.96***
MATCEMIB+	18	5.13	4.44	18	***6.92***	4.56	23	***6.62***	***5.59***	23	5.61	4.48

The Mann-Whitney U tests showed that the Control group from UoM outperformed that of RMIT statistically significantly both in the number (Z=-3.740, p<0.001) and the breadth (Z=-3.003, p<0.005) of ideas. The difference in performance between the MATCEMIB+ groups of RMIT and UoM was not statistically significant. No statistical significance was discovered between the corresponding groups from BUT, KNASTU and UoM.

Figure 2 offers a graphical interpretation of the breadths of ideas proposed by students of the Control groups from RMIT and UoM that are presented in Table 3.

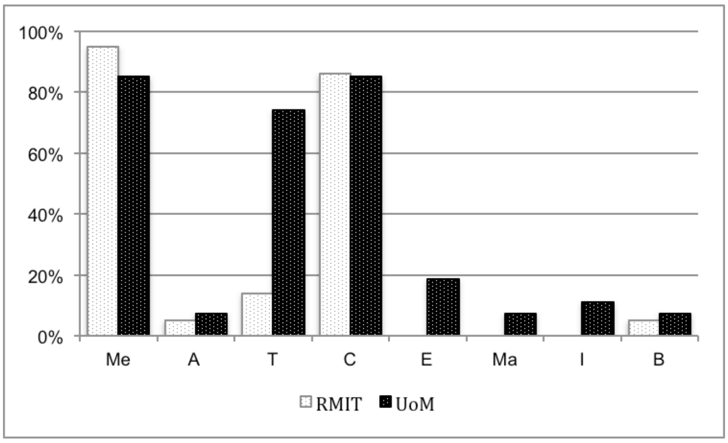

Figure 2: Percentage of students from Control groups of RMIT (light) and UoM (dark) that proposed ideas that belong to each field of MATCEMIB.

It can be noticed that the majority of students from RMIT suggested only solutions that belong to Mechanical and Chemical principles of operation (Breadth=2.05). At the same time, on top of the Mechanical and Chemical solutions, three quarters of the UoM students thought of solutions based on the Thermal principles of operation; nearly 20% also suggested ideas to remove lime build-up Electrically (Breadth=2.96).

Discussion

The overall results of the idea generation experiment at UoM, shown in Table 1, followed the pattern identified in previous experiments with students from Australia, Czech Republic, Germany, Finland, Italy and Russian Federation (Belski et al., 2015; Belski et al., 2014; Belski, Livotov, & Mayer, 2016). In particular, students from the MATCEMIB and the MATCEMIB+ groups outperformed their counterparts from the Control groups in both the number and the breadth of generated ideas. At the same time, students from the Random Word groups demonstrated mixed success; on some occasions, they did better than their counterparts from the Control group and on other occasions (as at the UoM) they did worse than their colleagues from the Control group. It remains to be seen why this is the case, however one possibility is that the random words may act as a distraction to some students that negatively affects their ability to generate ideas.

Only two out of three hypotheses of this study have been supported by the outcomes of the experiment.

The first hypothesis has been fully supported. The Control group from UoM statistically significantly outperformed the Control group from RMIT. Although this result supports the conclusion of Belski and Belski (2016) on the positive influence of science knowledge on the outcomes of idea generation, in this study the difference in performance between students from the UoM and RMIT could be explained by differences in many factors. The majority of the UoM students were from international (predominantly Chinese) background. They grew up under different cultural and language conditions and, most likely, had life experiences dissimilar to that of Australian students. These factors could have both boosted and inhibited student idea generation performance. Language differences, for instance, could have hampered the performance of the UoM students from an international background. The UoM students could have also had better creativity skills. The outcomes of the 2012 PISA assessment of creative problem solving positioned the 15-year-olds from four provinces of China that participated in the 2012 evaluation statistically significantly above their Australian counterparts (OECD, 2014). Students from Macao, Hong Kong, Shanghai and Chinese Taipei scored from 534 to 540 in the test. Australian students were on 523. Evidently, the results of the students from the four most economically advanced Chinese provinces cannot be generalised as performance of all students from China. However, it is possible that the creativity skills of international students from the UoM were above that of RMIT students.

The fact that the breadth and the number of the ideas proposed by students from the UoM Control group moderately and statistically significantly correlated with the science knowledge score (SK) favours the conclusion on the positive influence of science knowledge on the breadth and the number of distinct ideas made by Belski and Belski (2016). Clearly, the science knowledge score (SK) does not fully represent a student's knowledge in science. It does, though, offer adequate indication on the science knowledge that a student was exposed to. A person that studies physics is likely to be aware of more physical effects than a person who did not study physics. How would you, for example, propose to utilise electrolysis or cavitation if you have never heard of them? The absence of correlation between the knowledge score in mathematics (MK) and the outcomes of idea generation further supports the conclusion on the positive influence of science knowledge on idea generation.

It needs to be noted that the importance of general knowledge on creative performance has been advocated by Belski, Adunka and Mayer (2016). They surveyed engineering experts from some of the most innovative international companies and discovered that these experts value general knowledge (8.41/10) as much more important (statistically significantly) for creative performance then the discipline knowledge (7.00/10) and practical experience (7.21/10). General knowledge in terms of this experiment is represented by the science knowledge possessed by an individual student.

The second hypothesis has not been supported. The MATCEMIB+ group from the UoM was only slightly ahead of their RMIT counterparts on the count of independent ideas and their breadth but did not outperform them with statistical significance. The absence of statistical significance could be attributed to the significant representation of international students in the UoM MATCEMIB+ group; specifically, some international students might have had difficulties with English language. It is also possible that some international students, who came from different cultures, reacted to the MATCEMIB prompts differently to students from Australia and European countries. Overall though, the prompts appeared to work in improving idea generation – students from the MATCEMIB+ group outperformed their peers from the Control group in both the number and the breadth of ideas. At the same time, the eight words of MATCEMIB might have also confused some international students and inhibited the effect of the prompts. The latter explanation is supported by much lower performance of the students from the Random Word group compared to that of their Control group counterparts shown in Table 1. Such poor performance of the students from the Random Word group could likely be explained by the confusion created by the eight random words that were shown to them. Repeating the experiment at the UoM, in a semester when the enrolment ratio of local to international students is more in line with that from RMIT, may shed some light on the causes of the absence of a statistical significance between the MATCEMIB+ groups across institutions.

The third hypothesis has been partly supported. A moderate and statistically significant correlation was discovered between the number and the breadth of ideas generated and the science knowledge score (SK), but only for the Control group. None of the three experimental groups exhibited this correlation. This result implies that the experimental treatment (the words that were shown to students every two minutes) influenced the outcomes of their idea generation more than their prior knowledge in science, however this influence needs further investigation. Exploration of the level of school academic performance, as measured by ATAR score, and idea generation performance can further clarify the understanding of which factors influence the generation of ideas.

Conclusion

The findings of the study partly support the conclusion of Belski and Belski (2016). For the Control group students, who were not influenced experimentally, prior knowledge in science did matter when it came to generating ideas. Some students from the MATCEMIB+ group were likely to be influenced by the experimental treatment in a dual way. On one hand, it hinted to them the knowledge areas that held ideas on removing the lime deposit. On the other hand, the words shown to students without explanation could have puzzled some of them, particularly students from an international background. Consequently, further research is required to further clarify the influence of the experimental treatment on idea generation.

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