Australian electrical engineering curricula and development of creativity skills: How do we rate?

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SESSION S2: EDUCATING THE EDISONS OF THE 21ST CENTURY

CONTEXT Engineering employers consider the ability to innovate and be creative as useful employment skills. Unfortunately, it has been reported that the creativity skill of some undergraduate engineering students decreases throughout a degree, and that many students are likely to suffer design fixation and stay with the first idea that comes to mind during idea generation, inhibiting their ability to generate creative concepts and develop their abilities. Numerous educators advocate for increased focus on creativity material within engineering curricula; one demonstrated method of enhancing these skills is to directly introduce students to creative problem-solving approaches. This raises the question to what extent existing engineering programs include creativity-related content that aims to overcome these issues, as currently this is not quantifiably understood for Australian engineering programs.

PURPOSE To establish the extent to which students are exposed to creativity-related concepts and taught creativity-related heuristics in Australian undergraduate tertiary engineering programs, in order to comprehend whether Australian engineering programs actively assist in providing students with course material that enhances their ability to apply creative approaches and develop alternative solutions to a problem.

APPROACH A list of Australian Qualification Framework Level 8 engineering single degrees accredited by Engineers Australia (offered during 2017) with “electrical” in the degree title and which had available program handbooks was compiled, resulting in set of 34 distinct degree programs offered at 25 tertiary institutions. A list of all the core/compulsory courses that a student must complete as part of each program was complied. Each course outline/handbook (including course description, learning outcomes etc.) was then consulted to determine whether the course explicitly (i) discussed the concept of creativity and/or innovation within the field of engineering (ii) included material on the application of creative approaches to aid in developing alternative problem solutions. Courses were evaluated to either meet each of the criteria or not, based upon information in the course outline.

RESULTS Of the 34 programs and 919 core courses evaluated, a total of 20 courses at 17 institutions included explicit demonstration or explanation of the concept of creativity and/or innovation within the field of engineering. No programs were evaluated to include courses containing material that explicitly exposed students to, or required of application of, creativity heuristics or techniques. It was also established that very few courses required students to specifically demonstrate creativity and innovation in their stated learning outcomes.

CONCLUSIONS Results show an overall lack of curricula material aimed at exposing and teaching creativity skills within Australian undergraduate electrical engineering programs, as well as a widespread lack of curricula material which explicitly discusses the concepts of creativity and innovation within the field of engineering. In order for tertiary institutions to produce students who are able to be more creative and overcome inhibition to develop alternative concepts, it is recommended that programs adapt to incorporate learning outcomes that are specifically aimed at enhancing students’ creative thinking skills.

KEYWORDS Creativity, ideation, course outlines, learning outcomes

Introduction

The ability to show a “creative, innovative and proactive demeanour” is one of the expected competencies of an accredited professional engineer within Australia (Engineers Australia, 2011). Studies demonstrate that engineering employers place value on the ability of their employees to effectively demonstrate utilisation of skills relevant to this area (Male, Bush, & Chapman, 2010; Wickramasinghe & Perera, 2010).

Creativity is important to engineering, because it directly relates to a core component of problem-solving. Although there are numerous models that describe stages which comprise the problem-solving process (Belski, 2002), one stage is common amongst these models: the stage of generating solutions to the problem that is being faced. This stage is often referred to as the idea generation stage. Unfortunately, idea generation is a stage of problem-solving that engineering students tend to do poorly. Students can become easily hampered by design fixation and find it hard to develop alternative solution ideas (Condoor, Shankar, Brock, Burger, & Jansson, 1992; Kershaw, Holtta-Otto, & Lee, 2011; Samuel & Jablokow, 2010). Many students are likely to fixate on the first idea which comes to mind and find it hard to change their focus (Kershaw et al., 2011; Samuel & Jablokow, 2010), a situation made worse by spending insufficient time generating alternative solution ideas (Samuel & Jablokow, 2010). These traits can severely limit students’ ability to be creative. This does not suggest that students do not see the value in creativity-related material: the inclusion of creativity within engineering education is something which has shown to be positively valued by engineering students of all year levels (Waller, 2016).

It has been suggested by Daly, Mosyjowski, and Seifert (2014) that inclusion of creativity-related material within engineering programs is relatively rare. Numerous educators consider there is a need for increased focus on creativity and innovation material within engineering curricula in tertiary institutions (Atwood & Pretz, 2016; Cropley, 2015; Daly et al., 2014; Samuel & Jablokow, 2010; Tekic, Tekic, & Todorovic, 2015), as many engineering programs lack such content. Research has also concluded that engineering students who initially demonstrate a higher self-confidence in their creativity skills are less likely to complete an engineering degree, and are more likely to drop out (Atwood & Pretz, 2016). It may be considered that some students with higher levels of creative self-confidence may feel as though they are unable to effectively express and further enhance their creativity throughout an engineering degree. A recent study reported results that may support this notion; while the critical thinking capabilities of senior and freshman engineering students were found to be relatively similar, senior students were evaluated to overall be significantly less creative than their freshman counterparts (Sola, Hoekstra, Fiore, & McCauley, 2017).

These findings raise the consideration to what extent do Australian engineering programs currently engage students with creativity-related material. Existing research in this area primarily focuses on programs outside of Australia, and is often limited to the analysis of programs at one institution, such as studies conducted by Daly et al. (2014) and Marquis, Radan, and Liu (2017). This leads to the further consideration of how Australian engineering programs may further work to ensure that the creativity-related competencies set out by Engineers Australia (2011) are effectively enhanced during a four-year engineering degree. Currently it is not quantifiably understood to what extent Australian engineering programs engage students with creativity-related material.

Methodology

Assessing whether courses teach “creativity”

Attempting to determine if an engineering program may teach anything related to creativity, is clearly too vague without further clarification. For example, some educators may consider that in order to complete certain capstone or engineering design projects, it is *inferred* or *implied* that creativity must be shown, while other educators may advocate that creativity must be explicitly included within the learning outcomes of a course. As the role of an educator should ideally be to attempt to enhance the skills of the entire cohort where possible, it is important to not only consider whether engineering curricula cater for students who can effectively demonstrate creative skills, but aim to enhance the skills of those who struggle to do so. In order to evaluate how creativity is currently taught and may therefore be improved, it is required that meaningful and measurable criteria are utilised. This study will focus on evaluating whether courses *explicitly* cover selected material related to creativity.

One potential measure was evaluation of whether engineering programs include material which sufficiently explains the importance and concept of creativity within the domain of engineering. Inclusion of such material is likely to provide students with a more concrete understanding of how creativity and innovation relate to their chosen field of study, potentially resulting in students becoming more aware and engaged with the area of creativity and innovation. Explicit knowledge that engineering employers value these skills may also motivate students to seek out methods of enhancing their creativity.

It has been asserted by Genco, Hölttä-Otto, and Seepersad (2012) that "creativity, as part of the engineering design curriculum, is typically taught by introducing a set of ideation methods as part of a junior- or senior-level, or occasionally a freshman-level design class". This assertion is reflected by the findings of a study which discovered that faculty members from the field of engineering rated the generation of multiple ideas or outcomes as being the most important factor that was related to creativity (Marquis & Vajoczki, 2012). A second potential measure was therefore to evaluate whether engineering programs included material which actively demonstrates to students that it is possible to enhance their creativity skills by implementing structured processes that are designed for this purpose (i.e. creativity training).

Creativity-related heuristics and techniques

Creativity-related heuristics or techniques in this study refer to any structured processes that are designed to enhance a person's creativity when used, often by leading to the creation of additional solution ideas that may not otherwise have been thought of by the person. The ability to generate alternative ideas and consider ideas from various fields of knowledge or categories, are often used as core metrics to assess creativity (Cropley, 2000). Such creativity-related heuristics or techniques may include (but are not limited to) Brainstorming, Mind mapping, 6-3-5, C-sketch, Six Thinking Hats and Random Word by Edward de Bono (De Bono, 1988) and TRIZ (Russian: teoriya resheniya izobretatelskikh zadach, English: theory of inventive problem solving) methodologies.

Compiling details of Australian electrical engineering programs

This study is limited to the consideration of programs that adhere to the requirements of Australian Qualifications Framework (AQF) Level 8, and only covers the sub-discipline of electrical engineering, due to resource and scope constraints. AQF level 8 corresponds to a bachelor honours degree program (Australian Qualifications Framework Council, 2013). For Australian engineering programs, this comprises undergraduate engineering programs completed over four years full-time.

In order to evaluate whether Australian electrical engineering programs expose students to creativity-related material, a list of applicable programs was required. A list of AQF Level 8 engineering degrees accredited by Engineers Australia (2017) with the words "electrical" and "engineering" within the degree title was compiled. Double or dual degree programs were excluded, only single degree programs were considered for analysis. This list was then reduced to include all programs for which an applicable program structure was publicly accessible from the host institution's website, resulting in a set of 34 distinct degree programs offered at 25 tertiary institutions. Distinct refers to the fact that each program has a unique title; several programs at the same institution may include the same course.

For each program, a list of all the core or compulsory courses that a student must complete in order to graduate from the program was compiled. All forms of electives courses were excluded from consideration as the aim was to establish whether a program *ensured* that a student was exposed to creativity-related course material, not only whether the program provided students with the *opportunity* to be exposed to creativity-related course material. Ideally, if engineering educators wish to enhance the creativity-related knowledge and skills of students, such material should be incorporated in a way that it clearly forms part of the intended learning outcomes for at least one core course within the program.

Criteria for analysing course outlines

For each of the 34 unique degree programs, the course outline or handbook (including course description, learning and teaching activities, expected deliverables, learning outcomes etc.) of every compulsory course was then accessed by means of the applicable institution's website. The information contained within the course outline was then consulted to establish whether it may be argued that the course was likely to meet one or both of two selected criteria. Analysis of online publicly available course outlines has previously been used by Marquis et al. (2017) to assess how creativity instruction varied across disciplines at a tertiary institution, although the process of how course outlines were analysed was different. Both criteria were considered and analysed independently, so a course was able to meet the first criterion but not the second, or vice-versa.

The first criterion was whether the course *explicitly* introduced the concept of creativity and/or innovation within the field of engineering. This included, but was not limited to:

- Description of how creativity, innovation or ideation may be a part of the problem solving or engineering design process. For example, demonstrating a model of the problem-solving process and highlighting that "developing several alternative solution ideas" (or similar wording) is often modelled as the second of four primary stages.
- Providing information that allows students to understand that there are methods, heuristics or techniques designed to enhance creativity (such as mentioning that Brainstorming, TRIZ, 6-3-5 or C-sketch techniques exist), but students are not actually shown the detailed process of how to apply such processes.
- Case studies or analysis of people that have worked in engineering-related fields and are considered to have been creative. For example, analysis of what made the person "creative" or "innovative", and how the student may learn from this.

The second criterion regarded whether the course *explicitly* included material on the utilisation or application of creativity-related heuristics and techniques. This included, but was not limited to:

- Students are shown the detailed process of applying specific creativity or ideation-related heuristics or techniques by an educator (such as Brainstorming, TRIZ, 6-3-5 or C-sketch techniques), but may not be required to apply the technique themselves.
- Students are expected to apply a nominated creativity-related heuristic or technique to a problem, in an active learning manner (such as Brainstorming, TRIZ, 6-3-5 or C-sketch techniques). It did not matter whether students' work was assessed or not.

Courses were evaluated to either meet each criterion or not, based upon information in the course outline on the applicable institution's website. Courses were evaluated to not meet criterion where the course outline only claimed to meet section 3.3 ("Creative, innovative and pro-active demeanour") of the Stage 1 competencies set out by Engineers Australia (2011). It was required that the course outline made clear how this was actually achieved through course content, and so for the purposes of this study, met the criterion.

Procedure for analysing course outlines (Data analysis)

To analyse each course, an independent spreadsheet was created for each engineering program. The list of compulsory courses within each engineering program was then listed on the applicable spreadsheet. Analysis was conducted in two stages. The first stage aimed to reduce the list of courses in each program to those which may reasonably be considered to meet either of the two criteria based upon text within the course outline, even if the link may be rather vague. This included (but was not limited to) mentioning words like “thinking skills”, “creativity” and “innovation” or any derivation (such “creative” or “innovate”). The second stage introduced a form of inter-rater reliability, by reducing the list of courses to those which were more likely to be widely accepted as meeting one or both of the two criteria.

During the first stage, one assessor evaluated the content contained within the course outline or handbook for each compulsory unit within each engineering program. This resulted in the analysis of 919 courses from 34 independent engineering programs. In this stage, the assessor evaluated whether it was possible for each course outline to reasonably be linked to meet either the first and second criterion. As previously described, where it was established that a vague link may be made, the course was not excluded. Courses were included where they provided details that were somewhat analogous to the example situations previously mentioned, or included any information which may reasonable be interpreted as somewhat covering the concept of creativity in engineering, or use of application of creativity-related processes. This resulted in 877 of the original 919 courses being excluded during the first stage, with 42 unique courses being considered to potentially fulfil either one or both of the two evaluation criteria.During the second stage of analysis, three different assessors that were not part of the first stage of course evaluations, were provided with a list of all courses that were not selected for exclusion during the first stage. Each assessor then independently reviewed each course outline, and evaluated whether the course independently met either one or both of the two provided criteria. Results of these evaluations were then checked for agreement. For instances where at least two of the three assessors evaluated that a course met a certain criterion, the course was deemed to have met that criterion and was recorded. Otherwise, the course was recorded as not meeting the criterion.

Results

Results of the second stage of analysis showed that out of the 34 unique engineering programs assessed, there were a total of 17 programs which included at least one course which met the first criterion and discussed the concept of creativity and/or innovation within the field of engineering. Considering all of the 919 compulsory courses that were assessed, it was established that 20 courses were deemed to meet the first criterion and discussed the concept of creativity and/or innovation within the field of engineering.

Of the 34 unique engineering programs that were assessed, it was established that no programs included courses that met the second criterion and included material on the application of creativity-related heuristics and techniques. Although some assessors evaluated some courses as meeting criterion 2, there was never an agreement between assessors that any course met the criterion.

Discussion

Reflecting on the results of this study, it was found that only half of Australian undergraduate electrical engineering programs include content which explicitly engage students with actively and purposefully learning how creativity relates to their domain of study. Where such material is included, it is usually restricted to one course within the program. Additionally, very few programs (if any) were found to include discussion on how students may work to improve their own creativity skills. Inclusion of course content which aims to explicitly expose students to creativity-related material appears to be relatively rare, suggesting that students are likely to have few opportunities to learn about the topic of creativity during the four years taken to complete an engineering degree. At a minimum, these outcomes demonstrate that it is rare for courses to incorporate learning outcomes that are explicitly related to creativity. These outcomes are similar to those of Marquis et al. (2017), who evaluated that only 1% of the total 149 engineering course outlines at a Canadian tertiary institution contained explicit references to creativity. Overall, the outcomes of this study confirm the conclusions of Daly et al. (2014), that inclusion of creativity-related material is relatively rare within engineering programs. The assertion of Genco et al. (2012) that creativity in the engineering curriculum is usually taught by introduction of ideation techniques, also does not appear to be an accurate depiction of engineering curricula within Australia.

The findings of this study suggest that creativity is overall given a low priority within existing engineering curricula. Educators may assert that students are implicitly exposed to the topic of creativity and sufficiently build upon related skills through situations which allow students more freedom of design, such as capstone or engineering design projects. However, where one of the intentions of a course is to develop creativity-related knowledge or skills, it should ideally form one of the clear learning outcomes for that course. A core issue exists within a conclusion that creativity is sufficiently enhanced through current teaching methods Research has demonstrated that current. methods of exposing students to creativity-related material and enhancing creativity-related skills, does not necessarily lead to an increase in creativity and innovation related-traits over a four year engineering degree, in fact, significant decreases were reported (Genco et al., 2012; Sola et al., 2017).

The startling outcomes of this study have shown findings important both to engineering education, and engineering industry. Studies demonstrate employers place high value on creativity skills (Male et al., 2010; Wickramasinghe & Perera, 2010). In addition, recent reports have highlighted the need for creativity and innovation within Australian businesses, in order to be able to perform effectively and compete within the Australian economy (Deloitte, 2017; Department of Employment, 2016). It is clear that engineering programs may not consistently produce graduates who effectively meet this industry requirement. Adapting engineering curricula should be of utmost importance to curricula designers, to ensure that Australia will be able to produce engineering graduates who are able to meet this challenge.

There is a question of what may be done to try and address these findings. One previous suggestion is the introduction of short activities that are designed to expose students to specified creativity-related heuristics, as such activities may be accommodated into existing curricula restraints by being included in various courses throughout an engineering degree (Belski, Hourani, Valentine, & Belski, 2014). It has been demonstrated that introducing students to such heuristics can have real benefits to their creative performance, even after a period of three months (Valentine, Belski, & Hamilton, 2016). Such measures may allow educators to provide students with increased opportunities to work on enhancing their creativity skills throughout studying an engineering degree. If engineering programs are adapted to ensure that some courses provide students with an introduction to the topic of creativity in engineering, this may allow students to become more creative, innovative, and better meet the changing requirements of engineering industry. Additionally, it recommended that where courses intend to cover any creativity related topics, even if it is not a primary learning outcome of the course, that these topics are clearly outlined in the course guide of handbook. This will help comprehension of how engineering programs address the “creative, innovative and proactive demeanour” capability described by Engineers Australia (2011).

It is important to consider the limitations of this study. It is possible that the results presented in this study may not be able to generalised to reflect the entirely of engineering curricula within Australia. This study has been limited to undergraduate engineering courses in the electrical discipline. Programs of other engineering disciplines or postgraduate level may explicitly include creativity-related material at a higher rate. Engineering programs within Australia may also be different to other comparable countries. While outside the scope of this study, future research may aim to address these points by investigating whether the findings of this study are similar to that of other engineering disciplines within Australia, or how Australian electrical engineering programs compare to that of other counties. Ideally, two or more assessors may independently carry out the first stage of course outline or handbook analysis, and then compare which courses were commonly evaluated to match the criterion or not. This may lead to more reliable results. A large number of courses were excluded during the first stage of data analysis. However, it is imperative to consider the construction of engineering programs. Many programs consist primarily of courses which focus on the development and application of domain specific knowledge that is required in order to be able to work as an engineer; the majority of such courses focus on developing convergent-based problem-solving skills. As is reasonably anticipated, the vast majority of these courses do not contain material which is expected to relate to creativity.

A limitation of using course outlines to assess whether courses meet the two criteria is that the level of detail provided by tertiary institutions is not standardised and is subjective. Some institutions have shorter descriptions and less information, while others have longer descriptions with more detailed information which make it easier to assess if the course fulfils the criterion. It is unreasonable to expect that all course outlines will detail all material that is covered throughout the course. However, it must be noted that course outlines at a minimum are expected to describe the core details of what is covered or taught in the course. It can therefore be reasonably asserted that if a course outline does not contain details which explicitly relate to creativity, it is clear that the development of creativity skills is not likely to be a primary learning outcome for the course. Nevertheless, it is possible that certain courses may include material which meets either or both of the two criteria, but this information was not clearly included in the course outline and was therefore excluded.

Conclusion

Recent research has reported that the creativity skills of engineering students do not necessarily increase during the four years taken to study an engineering degree, despite that creativity is a skill industry seeks. This study investigated the extent to which Australian electrical engineering programs engage students with creativity-related material, to understand whether sufficient actions are currently being taken to address this concerning issue. Specifically, it was investigated whether programs explicitly included material which discussed the topic of creativity within the field of engineering, and explicitly included material on the utilisation or application of creativity-related heuristics or techniques. Course outlines for 919 core courses from 34 distinct electrical engineering programs (offered by 25 tertiary institutions) accredited by Engineers Australia, were evaluated. It was found that 20 courses (from 17 programs) offered at 17 institutions explicitly included material which discussed the topic of creativity in engineering, while not one of the 919 core courses evaluated included material on the utilisation or application of creativity-related heuristics or techniques. These findings confirm recent assertions of educators who note that creativity is not widely taught, and is generally given a low priority in engineering education. These outcomes demonstrate that teaching of creativity-related skills at many tertiary institutions is likely done through implicit methods such as completion of capstone projects rather than explicit methods, and may not provide many students with sufficient instruction to effectively build on their skills. In order for engineering graduates to better meet the challenges faced by industry, educators may need to re-assess how creativity is currently taught and whether students are currently provided with sufficient exposure and instruction in the use of creativity.

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