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The Impact of Excessive Focus on Performance During Engineering Design Process on Creativity*

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Creativity is considered to be a central requirement for engineering practice. Many studies have previously pointed different creativity blockers and the challenges of enhancing creativity in engineering education. However, there has been limited study on the relation of product performance (functionality) and product creativity in an engineering design education context. The purpose of this research is to ask how focus on product performance affect product creativity during the engineering design process. We seek to better understand the different levels of emphasis on performance and creativity during the engineering design process and their mutual relationship. To address this, a qualitative investigation was adopted in two engineering disciplines—one traditional in mechanical engineering and one relatively new in product design engineering. The main data collection methods were classroom observations and interviews with the students and instructors. 8 instructors and 8 students were interviewed. Learning materials of each studied unit such as unit outlines, project briefs and assessment rubrics were also analysed allowing for triangulation to be achieved. The findings show that the excessive focus on product performance during the engineering design process trivialises and diminishes the role of creativity. To enhance creativity in engineering education this study advocates challenging students with open-ended design problems, valuing the design process in addition to the design product, and allowing assessment for creativity; not purely performance. Our findings indicate that in addition to product performance, engineering instructors should emphasise product creativity in engineering design problem solving process. Future work is needed to understand the applicability of our results.

Keywords: engineering design education; design process; problem solving; creativity

1. Introduction

Engineering students need to have creative thinking skills in addition to their technical capabilities. Although creativity is expected from all engineering students in an engineering design process, nevertheless it is argued that the priority in engineering education is focused on the performance (functionality) of a product. This is not to say that product performance is not important. This research argues that the creativity of a product needs to be given as much importance as the performance of a product to educate the next generation of innovative engineers.

Engineering has too often portrayed itself as a discipline that recruits the top brains from the abstract realms of mathematics and science and shapes them into problem-solvers. However, it is noted that engineering might seem more attractive—especially to women—if instead it presented itself as a profession of creative, helpful problem-solvers who use math and science as some of their tools, not all [1]. In order to validate these claims this study looks at two different engineering disciplines in an educational setting: Mechanical engineering and product design engineering to examine the differences between the creativity understanding and approach to open-ended problems, where there is no single solution.

Similar to American architect Louis Sullivan's famous "form follows function" principle in an architectural and industrial design context—Does "creativity follow function (performance)" in an engineering design context? This study contributes to the understanding of product creativity vs. product performance during a problem-solving process in an engineering design education context and its impact on design project outcomes. While creativity in this context is never intended to replace performance, it is argued that the modern-day engineering requires both creative and performance metrics to meet the ever-changing demands expected from engineers. The engineering profession expects engineers "to recognise, validate, and solve problems" [2]. Basically, engineering is the ability of solving problems with a creative process [3] and "designing a novel artefact" [4, p. 417]. Engineering has always done and will always do problem-solving; therefore, the next centuries require more creative and novel solutions. In order to achieve this, engineers need to

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be as good in creativity as they are in technical knowledge [5]. The need for innovative engineers and creative problem solvers is universal [6]. Therefore, the aim should be to raise creative minded engineering students who also understand performance criteria. This study interrogates the requirements that need to be done in order to achieve this aim.

Current "traditional science model of engineering" curricula emphasise the basic science and mathematics for the initial years of the education [7]. Most importantly, it "focuses almost exclusively on lecturing" [8, p. 60]. There has always been a single approach in engineering education: "The professor lectures and the students attempt to absorb the lecture content and reproduce it in examination" [8, p. 57]. However, researchers [9] emphasise the role of design in learning engineering skills, practices and creative thinking. That is where students have the chance to experience creative thinking. However, creativity "gets killed more often than it gets supported" [10, p. 77]. This statement alone supports the intentions of this paper, which questions how the excess emphasis of product performance affects the creative process in an engineering design education context.

2. Background

Engineering and creativity are the "two sides of the same coin" [5]. Researchers [3, 11, 12] all suggest the reconstruction of undergraduate engineering education to make creativity a core part of the curriculum. Because, creativity is the basis for innovation [3]. Creativity was defined from an engineering perspective as "functional creativity" to indicate the importance of functional requirements in the engineering field [12]. In an engineering education context, creativity is the initial requirement in the innovation process. Creativity is the development of ideas; innovation is the application of ideas [3]. "Without creativity in design, there is no potential for innovation [13, p. 160]. However, there is a need for both in the engineering field. After examining a variety of descriptions for the term "creativity" of many other researchers, this study will use its own definition within the studied context [12, 14–19]:

> "Creativity empowers the engineer with ingenuity to tolerate the unconventional so as to generate original and non-obvious alternatives, which ultimately lead to better, innovative and worthwhile solutions to design problems."

Understanding how designers approach design helps engineering students to be successful in their studies [20]. If we investigate the difference between the creativity perspectives of engineering and design, it might give a clue about the creative processes. The primary focus of engineering is an artefact, whereas design education focuses on helping students understand and experience the process of realising an artefact [21]. Depending on the same protocol studies, researchers argue that during the design process, engineering students are more product and problem focused and performance driven. Whereas, design students are more process and solution focused and innovation driven [22–24]. The similarities and distinctions between designers and engineers are summarised: An industrial designer focuses on the product outcome and its development process, whereas a mechanical engineer is mostly related with the functionality and performance of the product [25].

Generating multiple solutions to a given problem is as important as coming up with a solution to the problem, because a productive creative process has an effect on the final product [26]. Mechanical engineers having high levels of engineering science knowledge, technical understanding and analytical skills; however, they lack creativity and design skills [27]. Product design engineering, however, stands between engineering and design. Product design engineering graduates can combine "the creative thinking of design with the analytical thinking of engineering" [28, p. 1]. The integration of industrial design and mechanical engineering develops creative and adaptive engineering designers who have a unique engineering pedagogy including 'designerly ways' of thinking [29].

There have been many studies investigating assisters and blockers to creativity in general [10, 30] and specifically in an engineering context [2, 17]. From an engineering perspective, creative pedagogy needs to consider some issues to overcome the current barriers to creativity: Staff development, creativity training to students, group work and a creative learning environment [3]. Focusing on the "one right answer" is a creativity blocker [30]. However, in engineering there is not only one answer, but should be a range of answers with varying positives and negatives.

Designers mainly deal with ill-defined or ill-structured problems [31]. They come up with solutions to design problems by determining the problem and solution together [32]. Open-ended design projects are developed to improve the design skills of engineering students. The designer needs to deeply explore the complex structured problems by not clearly seeing the solution at first sight. There are no right or wrong solutions; assessments are done whether the solution is good or bad [33]. There might be many variations of solutions to any given problem and these are related to how the problem is formulated [32]. Well-defined problems have a clear and defined goal and lead to a unique correct answer with no alternatives; by using known ways [31]. Whereas ill-defined problems do not have definite formulation and solutions to problems [32]. Many units in engineering curriculum teach analysis, which develop step-by-step style solutions to well-defined problems. This style does not help to solve design problems. The biggest difficulty in engineering design units is learning this new approach [34]. Giving open-ended questions to engineering students is a common way to increase creativity, because they allow multiple possible solutions and the possibility of generating alternative ideas [4]. Open-ended problems encourage divergent thinking [35] and they might have more than one acceptable solution [14]. Therefore, engineers need special training to successfully solve these problems [27].

A considerable number of researchers highlighted the necessity of improvement in creativity and innovation in engineering education [4, 27, 36]. Depending on their experimental investigation, engineering curricula need to undergo a reform "to strengthen students' innovation abilities throughout their undergraduate education" [37, p. 76]. "Education has a fundamental role in the promotion of creativity, but this should be modified, since students do not need to accumulate more knowledge, but to promote their creative potential" [38, p. 133]. In short, engineering education must be updated according to current requirements. However, many researches present "what engineering education should look like", but only a few describe "how this should happen" [39].

Exposing the next generation of engineers to the application of creativity should not be viewed as simply a particular program or the result of applying a fixed set of techniques [40]. Instead, creativity training should be subject to revision and extension as we develop a better understanding of creative thought and better understanding of the approaches that might be used to enhance creative thought [40]. The undergraduate engineering students must be educated to: "think across a variety of disciplines functionally as well as in terms of disciplinary depth" [11, p. 6]. It is important to focus on creativity early in the education process, starting from the first year so that it can be effectively introduced [36]. The majority of the studies [17, 26] have a holistic approach and argue that creativity and creative thinking should not only be integrated in the units but be inherently a part of the whole engineering curricula.

"Creativity has not been previously considered as a factor to predict engineering student persistence or achievement" [6, p. 540]. However, it is a criterion now. Among many assessment methods of creativity in literature, 'Creative Solution Diagnosis Scale' (CSDS) [5] is one of the newest creativity assessment methods suggested for assessing creativity in engineering and it is easy to understand. It considers previous assessment methods and develops a new one (building on the earlier ones) by suggesting a qualitative evaluation that can be turned into a quantitative evaluation. It measures the "kind of creativity" and "amount of creativity" of engineering products. Judges are expected to rate each indicator using a five-point scale [5]. The initial criterion is the "effectiveness", meaning the final product outcome needs to solve the problem it was supposed to do. First the product has to be effective, so that we can discuss about its creativity [5]. Being effective can be defined as being useful, fit or appropriate [14]. In order to motivate students to look for creative ideas, educators should assess the projects with both a creativity assessment and a numerical performance assessment [41].

Creativity research needs to be considered from various perspectives, because just looking at the research from one perspective misleads the researcher [42]. 4P framework [43] opens the doors into creativity research [42]. These Ps are the Person, the Product, the Process and the Press. In the context of this study, the Person is the student engineering designer, the Product refers to the produced outcome by the students, the Process is the approach to design outcomes and the Press refers to the environmental factors in play during the process. However, they do not operate in isolation from each other [5]. Some think product is the most powerful factor to be assessed in the design domain [44], whereas others claim the highest correlation is found between process and creativity [45]. Product results from process and it needs to be novel, unique and valuable to be creative [46]. For raising creative engineers, educators have a big role to play and this requires "flexibility in evaluation and diversification of assessment instruments, establishing a creative environment for the teaching-learning process, planning a system of rewards based not only on the results but also on the processes used" [38, p. 138].

Although many educators made improvements in engineering education, further advancement is required to develop a shared vision for transformative change [39]. Because creativity is "central to innovative problem-solving and it should be integral to the education of engineering designers" [27, p. 141].

3. Method

This study used a qualitative approach as "it helps people to understand the world, their society and its institutions" [47, p. 5]. Triangulation was made as it contributes to verification and validation of qualitative analysis by achieving findings through different data collection methods and different data sources [48]. It uses "similarities and differences in the data from different sources" to increase the rigor of research's progress [49, p. 58]. Each data source is expected to stand in each point of the triangle. The instructors had a good position in providing information about their own intentions and aims. The students were in the position to explain how the educators' actions influence their learning. The participant observer had the best position to collect data about all the instructor-student interaction [48, 50]. Therefore, data sources in this study were derived from the students who were taking the units, the product design engineering and mechanical engineering unit conveners and unit instructors, and the main author as the participant observer. The main data collection methods were observations, interviews and examining learning materials as follows.

3.1 Observation

Observation was the most significant method to collect data. Two engineering design units from mechanical engineering and product design engineering disciplines were observed at a university in Australia with strong engineering and design schools. The reason why a semi-structured observation was preferred is that it is neither based on "strict predetermined categories", such as in structured observation nor on "the larger patterns of behaviour", like in unstructured observation [50]. Following were the general questions that sought answers during the observations:

- How does the product development and design process evolve?
- In a problem-solving process are students more product focused or process focused?
- How does the interaction progress between the students and the instructors?
- What type of design problems are given? How are the problems structured?
- Are there any issues that might cause blocking the creativity?
- How is the assessment formulated?

3.2 Interviews

The data collection phase continued conducting semi-structured interviews with participants (students and the instructors of the units) aiming to get in-depth knowledge about their perceptions and experiences of creativity issues. In order to understand others and their perceptions or definitions, one of the most efficient approaches is to ask them [50]. Unstructured or semi-structured interviews just as important as observation in qualitative research and they are "more flexible and organic in nature" [47, p. 139]. The interview request was announced in the tutorials and students who wanted to participate notified the authors and then a suitable time was arranged for the interviews. The interviews took between 25–45 minutes each. There was no pressure for the participants to be involved in the interviews, however, all of the instructors of the studied units accepted to participate.

Some interview questions to instructors were:

- Is creativity an assessment criterion? Why/why not? Is it indicated in the class?
- Is creativity a bonus, or is it necessary? Do you think the students are aware of it?
- How do you give reward (grade, motivation) for creativity?

Some interview questions to students were:

- Can you please describe your idea generation process?
- What challenges did you meet in fostering creativity?
- Was creativity expected from you or encouraged in your design unit?

3.3 Surveys

Student Feedback Surveys (SFS) were analysed for the ME units that were observed. These surveys were conducted by the university at the end of each teaching term. The basic questions in this survey are:

- In my opinion, aspects of this unit that could be improved were. . .
- In my opinion, the best aspects of this unit were. . .

3.4 Learning materials

Learning materials of each studied unit such as unit outlines, project briefs and assessment rubrics were also examined to substantiate and support the findings. The engineering design units observed throughout the duration of one-year were as follows:

- Mechanical engineering—Machine Design (3rd year unit).
  - Observations in 2-hour/pw lectures and in two different 2-hour/pw tutorials.
  - Interviews with 5 instructors and 4 students.
- Mechanical engineering—Mechanical Systems Design (3rd or 4th year unit).
  - Observations in 2-hour/pw lectures and in two different 2-hour/pw tutorials.
  - Interviews with 3 instructors and 2 students.
- Product design engineering—Product Design Engineering Studio (2nd year unit).

  - Observation in two different sections of 2.5-hour/pw studio classes.
  - Interviews with 2 instructors.
- Product design engineering—Advanced Product Design (3rd year unit).
  - Observation in one studio of 2-hours/pw.
  - Interview with 1 instructor and 2 students.

All studied units were design units that have a problem-solving process and required a tangible solution to the given problem along with a report. The product design engineering units were design studio subjects and were taken by only product design engineering students. Whereas mechanical engineering design units were taken by mechanical engineering, product design engineering and robotics engineering students. They all had problem-solving in their content, which is supported by many researchers as an appropriate venue to foster creativity [36]. The studied product design engineering units and mechanical engineering tutorials had student numbers vary between 12 and 22.

This study had an interpretive approach. Therefore, the authors used various methods to access data and considered the commonalities in the collected data. The information was collected in various settings throughout two educational semesters (one-year), not just at a particular place in a limited time. In the end, the data was compiled and established a substantive total.

4. Results

The following abbreviations are used in this section:

ME-I. Mechanical engineering instructor.
ME-S. Mechanical engineering student.
PDE-I. Product design engineering instructor.
PDE-S. Product design engineering student.

The first stage of this study was to clarify the understanding of creativity amongst instructors and students. The results of this study showed that students' understanding of the key concepts of creativity harmonises with the instructors' perspective. Among the given characteristics of creativity, the majority indicated that "innovative" represents the characteristic of creativity or a creative output, which matches the creativity understanding of the authors.

The findings indicate that the excessive focus on functionality and performance during the engineering design process inhibits creativity. Three main points that affect creativity are examined further in this paper:

- Types of design problems.
- Assessment of design projects.
- The emphasis on the design process.

4.1 Challenging students with open-ended design problems

This study found different types of problems effected students' creative design process in a variety of ways. Even though the nature of the studied units were not exactly the same, they were considered the "design units" of mechanical engineering and product design engineering, where students need to show creative thinking. However, when we look at the design problems of both courses, it can accurately be said that product design engineering design problems were more open-ended than the design problems of mechanical engineering. To give an overview of the project context within mechanical engineering units "Machine Design" and "Mechanical Systems Design", the design problems presented for this particular study are as follows:

4.1.1 Mechanical engineering design problems

The main—and commonly preferred mechanical engineering project—was "to design and build a gear-box". Student teams were to design and build a gear-box from laser cut acrylic. It needed to lift a certain weight; a height and it will be powered by a standard electric motor. Even though the gear-box was a design problem, students found it more narrow-ended, which inhibited creativity.

Another project was the "ball-handling project". This project was "an ideal project for students who want more freedom and like the idea of something different" (Unit Outline). Students were required to design a module to be displayed. They could use any material, technique and technologies (electrical, mechanical etc.) to show aspects of different engineering techniques. However, due to its workload exceeding the semester-length, a minority of the students chose that project.

The main design project for Mechanical Systems Design unit was "the solar boat project": "Students are to take on a project to develop a solar powered boat using solar panels. Each boat will compete against the other boats in a race to one end of the pool and back. The assessment of the design project is done in a competition format that will be based on a round-robin" (Unit Outline).

4.1.2 Product design engineering design problems

For the product design engineering equivalent unit, students were tasked to design "The Microheat Project". This project was linked to novel water heating technology and students needed to utilise this technology to develop new energy efficient products. The primary objective of the project was to find new applications for the Microheat water heating technology within an allocated scenario and to prove that the application was viable: An open-ended problem.

It is argued that the type of design questions effects the creative process in different ways. Defined and closed-ended problems where the final product is obvious did not allow much creativity. On the other-hand, more open-ended problems encourage students to think more creatively. These results match those observed in earlier studies [33].

The distinctions between the problems were apparent when observing students during their design process. Students identified the difference of these projects very clearly:

> "The gear-box had an objective which is the weight it had to lift [. . .] You were going to get exactly these materials; you can use no more than that. Whereas with the ball-handling project you had to get a ball from point A to point B with no prescribed way of doing this. You can pretty much do that any way you want, using any material you want and any kind of process. So, I think just the fact that it was a lot broader in scope meant that we had more opportunities to show off our creativity. Creativity was more essential to the project because you had to be able to look at it in a different way [. . .]. It needs to be kind of exciting and different. It needs to be something that is reasonably 'out-of-the-box' and good to look at, whereas with the gear-box it was very much more like you have to do it this way and that's it" (ME-S4).
>
> "There is no creativity in the gear-boxes—It's more figuring out the maths, rather than envisaging how to make it. It's just making it work" (ME-S7).

One instructor agreed that "there are very big distinctions between the projects in terms of how they allow students to be creative, the ball-handling project is the best challenge that will help them" (ME-I1). ME-I5 said that, "The gear-box is more engineering calculations, whereas the solar boat certainly allows more scope for creativity". ME-I1 also supported that "the design of a solar boat is more creative than the gear-box". This evidence shows that more open-ended problems, such as the ball-handling project or the solar boat project, enhance creativity because it forces the student to solve ill-defined problems.

When we observed the product design engineering students who were working on the Microheat project, we noticed that the nature of the design problems in product design engineering were more open-ended when compared to mechanical engineering design problems. When the instructors were asked about the design problems PDE-I1 declared:

> "The problems that product design engineering students tackle are not necessarily well-defined problems [. . .]. In the product design engineering design process, we don't know what the outcome will be until we get there. It's different than other engineering disciplines in that it's a bit less defined" (PDE-I1).

"People who prefer the certainty of structured, well-defined problems will never appreciate the delight of being a designer" [32, p. 25]. Because most of the mechanical engineering students preferred well-defined problems to solve, they could not experience a comprehensive design process. However, just introducing open-ended questions without any planning about desired results and the assessment is not enough to improve creativity either [4]. The authors suggest that all engineering students should be exposed to more open-ended design problems in their educational life to trigger their creative thinking, as creativity is necessary for all engineering programs. If they continue to mostly focus on closed-ended (well-defined) problems, such as the gear-box, they will not expose themselves to the full creative process necessary for a modern engineer.

4.2 Allowing assessment for product creativity

Assessing only the performance (functionality) of the student's design project, but not the creativity of them inhibited students' motivation of coming up with innovative solutions. The assessment of the Machine Design unit in the mechanical engineering discipline was based on the following:

- Examination and Tests 50%.
- Design Performance 20%.
- Project Report 30%.

The performance of the gear-box was based on a formula, depending on the mass lifted, the height and the weight lifted, the time taken and the axial length of the gear-box. It also depended on the lowest and the highest performance achieved within the unit. Each team needed to submit a report explaining the design with suitable drawings, the key design decisions, documenting the modelling and calculations and reviewing the performance of the design. However, creativity appeared only as a criterion for the report writing and did not appear as a specific assessable outcome.

The assessment of the product design engineering design unit was divided as follows:

- Scoping and Ideation 20%.
- Detail Design 25%.
- Verification and Engineering Documentation 40%.
- Presentation 15%.

The major difference for this project is that it was an industry project for an actual client and was run as a competition that was judged based on the final student pitch to company staff. Microheat assessed the work against the following criteria: What's new and innovative in the proposal, quality of engineering and manufacturing proposal, aesthetics, presentation and potential market. The product design engineering instructors agreed that creativity was an assessment criterion for the design project:

> "It's a definite assessment criterion and it's structured on different sorts of levels" (PDE-I1).

ME-I1, ME-I2 and ME-I3 all agreed that there was nothing about product creativity in the mechanical engineering marking criteria, except a part of the report:

> "Creativity was supposed to be part of it, but we did not actually think about how to assess it" (ME-I1).

To have a deeper understanding of the creativity perception of both disciplines, product design engineering students who were also taking mechanical engineering design units provided a comprehensive perspective. They had the view of each discipline and were better positioned to make a comparison. PDE-S2, shared his/her thoughts:

> "One of the students made really small gear-boxes and they put a lot of effort in it, however in the end they didn't carry the 8 kg, which was the criteria. There were some huge gear-boxes which carried the 8 kg and they got better marks, even though 'making it as small as possible' was also a criterion of the problem, which was unfair. For the gear-box there's too much emphasis on performance [. . .] whereas in product design engineering it's very different. Performance isn't really a criterion. In the assessment, it's all about how much consideration is given to your design and definitely the amount of work you do" (PDE-S2).

Feedback Survey (SFS) results that were reviewed at the end of the year, supported previous comments: "The marking system for the gear-box seems unfair and does not necessarily reflect effort put in" (2015-MD-SFS).

It was observed in one of the mechanical engineering tutorials that students were explaining a creative solution to the problem that they came up with, but in the end, they decided not to pursue this. When the students were asked why they did not go for that particular solution, their response was straight—They were sure that they were not going to be awarded for being creative or innovative, so there was no need for the extra effort. They were told that only functionality was expected from them and there would not be any extra marks for creativity. This preference shows the ever-complicated compromise between a product function/performance, and its level of creativity. This situation supports what others [51] found that when students create more than one solution, they rarely select the original idea, because they "might not see originality as part of the definition for solving real-world problems" [51, p. 373]. Individuals can choose the less original ideas because they are less risky [52]. However, "being creative often involves—sometimes even requires—taking some degree of risk" [53, p. 225].

Obviously, the product's performance is integral to the success of the outcome, however, the level of creativity should not be compromised and always considered. If there is no assessment or encouragement for creativity in the projects offered, then the outcomes will rarely deliver this. It is argued that all engineering design projects should have an embedded assessment for creativity to at least 'force' the students to develop creativity. ME-I1 self-criticised their way of teaching because they give marks only to performance. As s/he states, "The criteria of marking must reflect what we want them to do, if it is creativity, let's give a mark to creativity" (ME-I1). Students need the opportunity to practice creative design skills. The university that set the curriculum need to offer opportunities to develop this skill and assess students on their progress [26]. Engineering students' design works are traditionally assessed by using rubrics; however, this is not a very reliable method. Alternative assessments methods are needed to efficiently assess students' abilities in engineering design [54].

The solar boat projects in Mechanical Systems Design were assessed in a competition setting. The assessment was depending on a formula; the variables were the lowest and the highest scores of other teams within the class. ME-I1 confirmed that some works were not creative but won the actual competition and inversely the ones that were actually creative lost because of performance issues. This contradicts what the unit convener said: "A good design is already a creative one". It was observed that too often creativity was mentioned and desired, but when it came down to assessment it was nowhere to be seen. The study shows that there is no direct relation between the performance of the design product and the creativity of it.

In addition to this competition, a creativity competition was also organised as an extra-curricular activity. Students were expected to assess each other's projects for creativity by using CSDS [5]. However, students were not trained to do peer reviewing previous to this activity nor they were encouraged enough to participate. This resulted in a lack of interest from the students.

The study shows that the mechanical engineering instructors' emphasis was implicitly on the product performance. This approach was directly echoed by the students' approach towards the design process. This mindset left creativity obscured behind functionality and performance. These findings support that the issue of excessive focus on performance during the engineering design process needs to be addressed if the intention is to enhance the use of creativity in the design process. The results of this study are consistent with findings that engineering programs do not reward creativity [4–6].

It is important to highlight that in mechanical engineering design units, the 50% of the marks were still allocated to exam and the tests. This was mentioned by the students too: "There is so much design and analysis work, that having a 3-hour exam is not particularly fitting the sort of work that we do" (2015-MD-SFS). The authors initially believe that the assessment should focus on the design part rather than the exam. Secondly, in the assessment of design works, assessing not only the performance, but also the creativity of the design works will encourage and motivate all engineering students for undertaking better creative thinking processes. These findings further support previous research [41], suggesting that instructors need to assess student works with both a creativity and a performance assessment in order to motivate their students to embody creative ideas.

4.3 Valuing the design process

One of the underlying issues about the challenges of enhancing creativity in engineering design education is the excessive focus on the design product rather than on the design process. The design process is an iterative process and takes time because it occurs in various stages. However, the emphasis during the design process in mechanical engineering was mainly on the performance of the final product. Product design engineering instructors emphasised the quality of the creative process rather than the quality of the final product while problem solving. They encouraged students to develop different ideas, always asking, "what's new here" (PDE-I1) and constantly promoted creative thinking. On the other hand, in mechanical engineering the focus seemed to be purely based on the final product. Our interpretations were validated with the student responses that mechanical engineering focused more about the final product, rather than the process of getting to the final product.

A product design engineering student, who also took the mechanical engineering design unit claimed, "In product design engineering, the end product is really important, but how you get there is just as important. . . In mechanical engineering, definitely the product outcome is the most important" (PDE-S1). Mechanical engineering students were asked if they thought about any alternatives to their designs. ME-S6 said that, "there was a couple, but we ended up going with the one that we thought was simplest and was the best as far as the scoring system goes" (ME-S6). They were asked if they pushed their ideas for creativity or not. The response was, "No we just went with what worked" (ME-S6). This approach shows how students focused just on functionality while developing their ideas. Students thought that they had to solve the problems only with a full-performing working product in order to meet the unit requirements. Although creativity was expected from all engineering students, nevertheless it is argued that current priority is on the product performance in mechanical engineering design units. We must also consider the instructor approach before concluding. PDE-I1 expressed her/his thoughts about creativity:

> "In a learning context, I am a real fan of process [. . .]. Creativity is about taking a risk that is harder in educational contexts [. . .]. I tend to favour my process and the student's ability to try lots of variables, lots of solutions to the problem. I would grade that higher than necessarily the final outcome even if the functionally needs refinement. Creativity is essential for problem-solving but also for risk taking [. . .]. If someone works through the process thoroughly, that ranks more heavily on the final grading than the actual outcome" (PDE-I1).

PDE-I2 also agreed assessing the process more:

> "The end product doesn't necessarily need to be as innovative or creative as we would have liked, however, learning the process is more important and that's what we mark on" (PDE-I2).

Product design engineering students were aware that creativity happens during the design process and they're less afraid of designing a product that can perform less, which allows them to think more creatively. On the other-hand, mechanical engineering students put so much emphasis on making the product perform they tend to forget about creativity and just focus on the performance of the product, which unfortunately neglects the benefits of the creative process. What this study is suggesting is there needs to be greater focus on creativity in engineering education, without compromising the product's function. It seems that product design engineering students understand creativity throughout the design process and know how to apply it but may compromise the products function. Likewise, mechanical engineering students understand the importance of a product's function but fail to develop the creative aspects of a product.

These claims are supported by one-year of observational research, semi-structured interviews and the detailed analysis of learning materials and surveys however, it is noted that this is confined to one reputable institution in Melbourne, Australia. While certainly relevant, we hope these research findings form the basis for other researchers in this field to expand to include other institutions working closely between design and engineering.

5. Discussion

This study provides valuable findings for the relation between product creativity and product performance (functionality) in an engineering design education context. In response to a growing interest in enhancing creativity in engineering education, this study offers new insights on the subject. The findings of this study show that the excessive focus on performance during the engineering design process—mostly observed in mechanical engineering design units—trivialises and diminishes creativity. Therefore, this needs to be addressed if the ultimate aim is to develop more creative engineers. We have found there are three main points that need to be addressed for fostering creativity during an engineering design process:

1. Design problems—Exposing engineering students to different types of design problems especially open-ended and less defined design problems.
2. Assessment—Considering the assessment of product creativity in addition to product performance focusing on design project rather than exam for assessment.
3. Design Process—Emphasising and valuing the design process as much as the design product.

The significant finding of this study is the impact of the performance emphasis during engineering design problem-solving on the development of the students' creative processes. This observation has not previously been described by the literature. Although creativity is expected from all engineering students, it is argued that the priority given to performance in engineering design subjects inhibits the development of creative thinking. Designing functional, effective [5] full performing products should undoubtedly be the core purpose of engineering disciplines. However, this must not deter creative input in design projects. Understanding the social, economic and environmental aspects of a product, while not compromising the products function, will ultimately ensure better quality products are produced. This will not be possible unless we educate our future engineers with an embedded understanding of creativity.

If a product does not meet the functional requirements expected, then there is no benefit of designing it. However, if some flexibility can be provided to students in a learning context it will allow them to think more freely. This is believed to release more creative thinking during the design process—even if in the earlier stages there are issues about performance, at least new and novel ideas can be generated, which can be refined at a later stage. The ability to 'push the boundaries' and create true innovation is much more difficult than ensuring the product performance. For this study, it is clear that product design engineering students are more creative, and mechanical engineering students are more technical. Both attributes are good, however, the modern-day engineer needs both of these skills to meet the changing demands of this discipline.

Therefore, we suggest that the emphasis on creativity needs to be increased in engineering design units. In order to do so, open-ended design problems that allow alternative solutions should be encouraged, while also ensuring a thorough understanding of the design process is taught. In order to increase the emphasis on the design process, assessment needs to be aligned with the desired purposes at all times. The generated ideas and the exhibited final outputs from the design process should both be considered in terms of their novelty and creativity. This study argues that assessing not only the performance of the final product but also the creativity of the design will encourage and motivate students to undertake better creative thinking processes. This will ensure students do not solely work with a functionality and performance mindset, but also add elements of innovation to their work process. Students should also be motivated to focus on creating multiple solutions during their design process to find the optimum outcome, rather than just focusing on the most functional, the easiest and the common one. It is important "not to focus on one solution too soon" [55]. Even if the well-known solution is chosen to be the best idea after going through an iterative process, students should validate this result by experiencing the design process entirety.

Valuing the design process is crucial. Because it takes time to develop creative ideas into innovative outcomes with commercial potential. During this time, failure is a part of learning. Engineering design education needs to understand this when assigning project tasks and assessment rubrics to students. An education environment is the best place to learn from failure during the design process as risks are not as severe as projects conducted in the professional world—both economically and socially. To contextualise this one of the world's most famous product design engineer James Dyson famously quoted the following in relation to the development of his bag-less vacuum cleaner:

> "I thought I'd get there quite easily. In fact, it took me five years and over 5,000 prototypes and it was frustrating. And actually, my life is a life of failure. There were 5,126 failures until I got the last one that worked. But during that journey you learn so much, because you learn from failure and you go and study it every day" [56].

It is true that if the bag-less vacuum cleaners designed by Dyson were not competitive in performance with the existing units, his innovations would never have materialised. But an engineering product needs to be "novel" too, in addition to being "effective" [5].

By applying a greater emphasis on creativity in engineering, we predict this will attract more females to study engineering, as creativity demands a diversity of viewpoints. Without input from women, engineers would have access to only half the total pool of creativity, constraining their ability to solve problems and limiting the applicability of the solutions they do reach. In an article in The Conversation, it was stated that the future generation of engineers need to truly reflect the society it serves—this is not just focused on gender, moreover it includes age, ethnicity, religion, physical ability and sexuality. Only then will it understand all the communities' engineers serve showing the importance of harnessing the widest variety of viewpoints available [1].

6. Conclusion

The objective of this research is to investigate using a qualitative approach how focus on product performance affects product creativity during the engineering design process. The study is focused predominately on mechanical engineering and product design engineering; however, it is suggested that all types of engineers need to build their creative skills. Product design engineering is fortunate to have creativity embedded in their program because of the close links to industrial design, which is something other engineering disciplines should leverage off. Product design engineering students are taught the necessary design and creative skills required to develop an innovative idea. It's not just the skills that are learnt; moreover, it's the design and creative process and the way in which these skills can be applied to any given problem. However, in mechanical engineering the case is different. In relation to mechanical engineering instructors, it seems their focus is predominately on the performance of the product being developed. This study suggests that the engineering instructors' focus needs to not only be on the product performance but also on the creativity and innovation involved in the development of the product. Only then, is it possible for the students to take risks in applying their creative thinking during problem solving, which is essential for product innovation. The relationship between product performance and product innovation is interesting and has important implications for enhancing creativity in engineering. This is an important issue for further research.

This study concludes that engineering students should be encouraged to learn from their design process rather than just focusing on their final outcome—because that's where novelty occurs. Design process must be valued at all times. All engineering students need to understand the importance of design process from early in their degree and they need to be assessed for their creative ideas generated in this process. Not only the performance of their products, but also their creative thinking must me valued and reflected to assessment. Students also need to practice many types of design problems—especially open-ended problems—to ensure they have the creative ability to adapt to the constantly changing world we live in. Because the future engineer needs to be agile, technically savvy and importantly, creative.

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