Product Performance vs. Product Creativity in Engineering Education

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CONTEXT
Literature suggests that engineers need to have creative thinking skills in addition to their technical capabilities. Many studies have previously pointed different blockers to creativity, some of which highlight the challenges of embedding creativity in engineering education. However, there has been limited study on the relation of product performance and creativity in an engineering design context. This study contributes to the understanding of creativity vs. performance in an engineering design context and its impact on final design project outcomes.

PURPOSE
This study aims to examine how much the different levels of emphasis on functionality and performance impact the final design outputs in the engineering design process.

APPROACH
This study compares the creativity approach in two engineering disciplines – one traditional in Mechanical Engineering (ME) and one relatively new in Product Design Engineering (PDE). To do this, two engineering design units from each discipline have been observed throughout the duration of a year. Interviews were done with the instructors and students to substantiate the findings and results of this study show the differences between the creativity perceptions in ME and PDE pedagogies.

RESULTS
Although creativity is expected from all engineering students, nevertheless it is argued that currently the priority is focused on the product performance in ME design units. These findings suggest that excessive focus on performance during the engineering design process needs to be addressed for fostering creativity. The students narrow focus on the end product should be expanded to enable a broader perspective that encompasses all stages of the design process.

CONCLUSIONS
It is argued that ME students should be exposed to more open-ended design problems to trigger their creative thinking. They should be encouraged to learn from their design process by generating alternative solutions rather than just focusing on the final product. In order to increase the emphasis on the design process, assessment needs to be aligned with the desired purposes at all times.

KEYWORDS
Engineering Design Education, Creativity, Product Performance Design Process.

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Introduction

How much impact does different levels of emphasis on functionality and performance have on the final design outputs in the engineering design process? In order to answer this question, this study examines the differences between the creativity understanding of two different engineering courses: Product Design Engineering (PDE) and Mechanical Engineering (ME). Because, creativity during the design process is understood and approached differently in various disciplines.

The findings show that the excessive focus on performance during the engineering design process — mostly observed in ME design units — trivialises and diminishes creativity. Therefore, this needs to be addressed if the ultimate aim is to develop more creative engineers.

Many studies have previously pointed different blockers to creativity and some of them (Zhou, 2012a; Kazerounian and Foley, 2007) highlight the challenges of embedding creativity in engineering education. However, there has been limited study on the relation of performance and creativity in an engineering design context.

This study contributes to the understanding of creativity vs. performance in an engineering design context and its impact on final design project outcomes. The findings resulted from the qualitative research that the authors conducted in the 2015 educational year will also be used to conduct action research in engineering design units with the aim of increasing creativity in engineering education.

Terminology and abbreviations used in this study:

Course: the entire program of studies offered to complete a university degree

Unit: a module of teaching that generally lasts one academic semester

Mechanical Engineering Instructor/Student: ME-I / ME-S

Product Design Engineering Instructor/Student: PDE-I / PDE-S

Background

A considerable amount of researchers highlighted the necessity of improvement in creativity and innovation in engineering education (Baillie & Walker, 1998; Daly et al., 2014; de Vere, 2013; West et al., 2012). “Engineering is a problem solving process that connects new needs to new technologies. Creativity is concerned with the generation of effective, novel solutions; and therefore, creativity and engineering are, in essence, two sides of the same coin” (Cropley, 2015, p. 22). de Vere (2013) — when questioning the new directions in engineering education — claims “creativity is central to innovative problem solving and it should be integral to the education of engineering designers” (p. 141). The engineering profession expects engineers “to recognise, validate, and solve problems” (Liu & Schonwetter, 2004). Basically, engineering is the ability of solving problems with a creative process (Zhou, 2012a) and “designing a novel artefact” (Daly et al., 2014, p. 417). Engineering has always done and will always do routine problem solving, however the 21st century requires more creative and novel solutions. In order to achieve this, engineers need to be as good in creativity as they are in technical knowledge (Cropley, 2015).

Cropley and Cropley (2010) define creativity from an engineering perspective as “functional creativity” to indicate the importance of functional requirements in the engineering field. Cropley (2015) suggests a method of assessing product creativity in an engineering context. His first criterion is the “effectiveness”, meaning the final product outcome needs to solve the problem it was supposed to do. If the product is not effective, then it doesn’t matter how surprising or original it is. “There can be no discussion of creativity without first dealing with the issue of effectiveness” (Cropley, 2015, p. 67).

If we have a look at the difference between the creativity perspectives of engineering and design, it might give a clue about the creative processes. Sheppard & Jenison (1996) see the primary focus of engineering is an artefact, whereas design education focuses on helping students understand and experience the process of realising an artefact. The quality of the artefact has a secondary importance. Mann & Tekmen-Araci (2014) — depending on dataset protocol studies — argue that during the design process engineers are more focused on the product rather than the design process when compared to Industrial Design (ID) students. This is also supported by Goldschmidt et al. (2014) who worked with the same protocol arguing that ME is performance driven and product focused whereas ID is innovation driven and process focused. Similarly, Gero & Jiang (2014) agree that ID students are problem-focused whereas ME students are solution focused.

PDE, however stands in between ME and ID. PDE graduates are capable of “successfully combining the creative thinking of design with the analytical thinking of engineering” (Kuys et al., 2014). The integration of ID and ME develops creative and adaptive engineering designers who have a unique engineering pedagogy including ‘designerly ways’ of thinking, which is a phrase by Cross (2001). Kuys et al. (2014) summarise the similarities and distinctions between PDE, ME and ID from a design perspective: An industrial designer is focuses on the product outcome and its development process, whereas a mechanical engineer is mostly related with the functionality and performance of the product. de Vere (2013) sees mechanical engineers having high levels of engineering science knowledge, technical understanding and analytical skills; however they lack creativity and design skills (de Vere, 2013). Promoting creativity is the biggest challenge when teaching a design approach to engineering students (Kuys & de Vere, 2010).

There have been many studies investigating assisters and blockers to creativity in general (Amabile, 1998; Treffinger et al., 2005; de Bono, 1993; Runco, 2007) and specifically in an engineering context (Liu and Schonwetter, 2004; Richards, 1998; Kazerounian and Foley, 2007; Wang, 2007). Treffinger et al. (2005) lists some myths and misconceptions about creativity which might obstruct creative thinking: Believing that not being a creative person, thinking that creativity cannot be taught, seeing it equal to art or as madness (Treffinger et al., 2005). de Bono (1993) mentions the misbelief of releasing the mind will bring all the creative ideas. It is worthwhile to break out the “one right answer” judgement system for the sake of freethinking, but just freeing the people up does not necessarily bring sudden creative ideas either (de Bono, 1993). 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 (Daly et al, 2014). Many units in engineering curriculum teach analysis, which develop step-by-step style solutions to well defined problems. Whereas, design problems are usually ill defined and the step-by-step linear way of learning does not help. The biggest difficulty in engineering design units is learning the new approach (Zemke & Zemke, 2013).

From an engineering perspective, creative pedagogy needs to address some issues in order to overcome current barriers to creativity: “Facilitating staff development, providing creativity training to students, encouraging group work and building a creative learning environment” (Zhou, 2012a, p. 352). Kazerounian and Foley (2007) summarise some barriers to creativity in engineering education: Thinking engineering is a “serious business” misleads engineers to be accurate not creative. There is a belief that engineers cannot take risks like artists or musicians, because engineers might cause loss of lives as they are building automobiles or bridges. In short, “creativity is not valued in the contemporary engineering education” (Kazerounian & Foley, 2007, p. 762).

Amabile (1998) is concerned that creativity “gets killed’ much more than it gets supported. This statement alone supports the intentions of this paper, which questions how the excess emphasis of product performance affects the creative process and product in an engineering design context.

Method

This study uses a qualitative approach as "it helps people to understand the world, their society and its institutions" (Tracy, 2013, p.5). It questions the relation between product performance and product creativity in an engineering design process by comparing the approaches in two different engineering disciplines: ME and PDE. Two engineering design units from each discipline were observed throughout the duration of a year in a prominent university in Australia with a strong engineering and design school. The data collection phase continued by conducting semi-structured interviews with participants aiming to get in-depth knowledge about their perceptions of creativity issues. Learning materials of each unit such as unit outlines, project briefs and rubrics were also examined.

Triangulation is made as it contributes to verification and validation of qualitative analysis by achieving findings through different data collection methods and different data sources (Burns 1997, p. 325). It uses "similarities and differences in the data from different sources" to increase the rigor of research's progress (Cherry, 1999, p. 58). Each data source is expected to stand in each point of the triangle. The teacher has a good position in providing information about his/her own intentions and aims about the situation. The students can best explain how the teachers' actions influence their way of learning. The participant observer is in the best position to collect data about all the observable features of the teacher-student interaction (Burns, 1997; Punch, 2009). Therefore, data sources in this study were derived from the students who are taking the units, the PDE and ME unit conveners, unit instructors and the researchers. The main data collection methods are observations, and interviews. The information was collected in various settings throughout two educational semesters, not just at a particular place in a limited time. In the end, the data was compiled and established a substantive total.

The authors investigated two engineering design units from each course throughout the 12 week semester:

- ME- Mechanical Systems Design
  - Observations in 2-hour lectures and in two different 2-hour tutorials
  - Interviews with 3 instructors and 2 students
- ME- Machine Design
  - Observations in 2-hour lectures and in two different 2-hours tutorials
  - Interviews with 5 instructors and 4 students
- PDE- Product Design Engineering
  - Observation in two different sections of 2.5-hour studio classes
  - Interviews with 2 instructors
- PDE- Advanced Product Design
  - Observation studio part 2 hours per week
  - Interview with 1 instructor and 2 students

The PDE units are design studio subjects and are taken by only PDE students. Whereas ME design units are taken by ME, PDE and Robotics Engineering (only Machine Design) students. They all have problem solving in their content, which is supported by many researchers as an appropriate venue to foster creativity (de Vere 2009; Kuys & de Vere, 2010; Dym et al. 2005; Treffinger et al. 2002). The studied PDE units and ME tutorials had student numbers vary between 12 and 22.

Observation has been the most significant method to collect data. The reason why a semi-structured observation is 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 (Punch, 2009). Following are the general questions that sought answers during the observations:

- How does the product development/design process evolve?
- In a problem solving process are students more problem focused or solution focused?
- How does the interaction progress between the students and the instructors?

- Do the instructors give promotion for creative works? Is there a motivation for it?
- What type of problems are given? How are the problems structured?
- Are there any issues that might cause blocking the creativity?

In order to understand others and their perceptions or definitions, one of the most efficient way is to ask them (Punch, 2009). Burns (1997) finds unstructured or semi structured interviews are as important as observation in qualitative research and they are "more flexible and organic in nature" (Tracy, 2013, p.139).

The interview request is announced in the tutorials. Students who wanted to participate notified the authors and then a suitable time was arranged for the interviews. The interviews took about 25-30 minutes each. The instructors are interviewed about 40-45 minutes. Interviews with the instructors are made separately due to respecting every instructor's different way of teaching and interpretation. There was no pressure for them 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 it a bonus, or is it necessary? Do you think the students are aware of it? How do you give any reward (grade, motivation) for creativity?

Some interview questions to students are:

- Do you think a competition environment increases or decreases creativity? How?
- Can you please describe your creative process of idea generation for the design projects?

This study had an interpretive approach and the authors were aware of the subjective nature of the interpretations. That's why we have been transparent about our own subjectivity by looking from a researcher's perspective and supressing our educator identity as much as possible. Therefore, we used various methods to access data and considered the commonalities in the collected data.

Findings and Discussion

It is worth to explain that the first step was to clarify the understanding of creativity among instructors and students. The survey results done in two consecutive educational years show that students' understanding of the key concepts of creativity harmonizes with instructors' perspective. Among the given characteristics of creativity, the majority indicated that "innovative" represents the characteristic of creativity or a creative output. Then"imaginative" and "functional" come respectively.

The impact of different design problems to creativity

When we look at the design problems of both courses, it can accurately be said that PDE design problems are more open-ended than the design problems of ME. To give an overview, the problems presented for this particular study are as follows: Machine Design offered 4 different problems, 3 of which demand an increased effort and a longer time than the usual semester-length. Therefore, most of the students preferred the simple, least open-ended problem due to less commitment and requirements. The most preferred problem in this case was "to design and build a gear-box". Student teams are 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.

For the PDE equivalent 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 is to find new applications for the Microheat water heating technology within an allocated scenario and to prove that the application is viable: an open-ended problem.

The distinctions between the problems were observed when looking at the students working both with the “gear-box” project and the “Microheat” project. Even though the gear-box was a design problem, students find it more narrow ended which inhibits creativity. One response from a ME student was as follows: “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). When we look at the PDE students who are working on the Microheat project, we observe that the nature of the design problems in PDE were more open-ended when compared to ME design problems. When we ask the instructors about the design problems PDE-I1 argues, “The problems that PDE students tackle are not necessarily well-defined problems. Whereas I see a lot of engineering projects that students show me and there’s a set of criteria and an agreed end point where they know what the outcome will look like. In the PDE 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). Similarly, ME-I1 argues that design problems are a good way for the students to be creative but when a design component is just about the end product but not the process, it’s a big challenge. “Because creativity does not come in the product, it comes in the process when you are solving the problems” (ME-I1). Accordingly, students care only about the product, because for students it’s all about where the marks are allocated. “If the emphasis is on the final product outcome, that’s what they care about the most” (ME-I1).

As Cross (2008) put forth “people who prefer the certainty of structured, well-defined problems will never appreciate the delight of being a designer”. Because most of the ME 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 (Daly et al, 2014). For ME students, they need to understand the design process from early in their degree and to practice many types of design problems. PDE students have many shared units in first year with ID, teaching them the necessary design skills required to develop an innovative idea. It’s not just the skills that are learnt; moreover, it’s the design process and the way in which these skills can be applied to any given problem. The authors suggest that ME students should expose more open-ended design problems in their educational life to trigger their creative thinking.

Assessment of design projects

It is argued that creativity must be encouraged and assessed for more student involvement and motivation about creative thinking. If educators encourage creativity, the students will be more enthusiastic about attempting it (Kazerounian & Foley, 2007).

The assessment of the ME unit is based on the following: Examination 40%, Tests 10%, Design performance 20 % and Project report 30%. The performance of the gear-box is 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 depends on the lowest and the highest performance achieved within the unit. Each team needs to submit a report explaining the design with suitable drawings, the key design decisions, documenting the modelling and calculations and reviews the performance of the design. Creativity appears only as a criterion in the report.

The assessment of the PDE unit was divided as follows: Scoping and Ideation 20%, Detail Design 25%, Verification and Engineering Documentation Deliverables 40% and Presentation Pitch Deliverables 15%. However, this is a real project for a real 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.

PDE instructors all agree that creativity is an assessment criterion for the design project: "It's a definite assessment criteria and it's structured on different sorts of levels" (PDE-I1). On the other hand, ME instructors' responses vary. They all agree that there was not much about product creativity in the marking criteria. One of the instructors said, "creativity was supposed to be part of it", but they did not actually think about how to assess it (ME-I1), and "it was not the main assessment criteria" (ME-I2).

To have a deeper understanding of the creativity perception of both disciplines, PDE students who are also taking ME design units provided a comprehensive perspective as they have the view of each discipline and are better positioned to compare them. 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 criteria of the problem, which was unfair. For the gear-box there's too much emphasis on performance… Whereas in PDE 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). Similar to "form follows function" as Louis Sullivan indicated in an architectural and industrial design (ID) context — Does "creativity follows function/performance" in ME design context?

It was observed in one of the tutorials that students were explaining their instructors a creative solution to the problem that they came up with, but in the end they decided not to do this project, because it was complex. Then it was asked the students 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 extra effort. They told that only functionality was expected from them, and there would not be any extra marks for creativity.

This shows the ever-complicated compromise between a product function/performance, and its level of creativity. Obviously the products 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 'push' 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 — which while subjective at times — will at least 'force' the students to develop this. The authors believe that assessing not only the performance but also the creativity of the design works will encourage and motivate students for undertaking better creative thinking processes.

Another factor was the exam in ME, unlike PDE. It is observed that ME students tend to focus more on the exam, rather than the design project. Students mostly used tutorial hours to get prepared for the exam. ME-I1 supported this observation by indicating that when the exam was 40% the attention was there. "The criteria of marking must reflect what we want them to do, if it is creativity, let's give mark to creativity". Then they would get benefit from the tutorials more (ME-I1). Observing that ME students spent a lot of time in preparing for the exam that was worth 40% and sacrificing their design projects for this, the authors suggest considering alternative methods to examination to assess student knowledge in a design unit for more creative thinking.

The emphasis during the design process

The design process is an iterative process and takes time because it occurs in various stages such as preparation, incubation, illumination and verification, as Wallas (1926) historically described. Even though both instructors studied in this area of the paper believed the importance of the process in a design class, their approach to the situation is different. PDE instructors emphasise the quality of the creative process rather than the quality of the final product. They encourage students to develop different ideas, always asking, "what's new here" (PDE-I1), and promote creative thinking. However, in ME the focus seems to be purely based on the final product. Our interpretations are validated with the student responses that ME cares more about the final product, rather than the process of getting to the final product.

A PDE student, who also takes the unit Machine Design claims, “In PDE, the end product is really important, but how you get there is just as important… In ME definitely the product outcome is the most important.” (PDE-S1). ME students admitted that they go with the easiest solution first to build a working product, then some groups kept the design and some tried to make it more creative: “We just basically picked a design we thought would be easiest to translate into real life… we mostly just build the design. We looked up a few articles and the literature review and then from there we had various designs which we narrowed down to one; built it; tested it; it worked so we kept it that design” (ME-S6). It clearly shows that the time constraint of 12-weeks semester influenced the choice of the simplest design to implement. Therefore, instructors must be there to help students in managing their time effectively to experience a fruitful design process.

We must also consider the instructor approach before coming to a conclusion. PDE-I1 expresses 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… I tend to favour looking at assessment as a process. If someone works through the process thoroughly, that ranks more heavily on the final grading than the actual outcome” (PDE-I1). PDE-I2 also agrees to assess more process: “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”.

Although both course instructors of the disciplines think in a similar way, students think differently. In a ME context, the idea of ‘the product has to work in the end’ brings many constraints and some students prefer to play it safe by not taking any risks. If you come up with a working solution, you meet the expectations; however, PDE is not satisfied with just a working solution but goes beyond it. In short, PDE students are aware of the fact that creativity happens during the design process and they’re less afraid of failing (in the context of a working solution and not in the context of the unit assessment), which allows them to think more creatively. On the other hand, ME students put so much emphasis on making the product perform well, they tend to forget about creativity and just focus on the performance, which unfortunately misses the benefits of the design process.

It takes time to develop creative ideas into innovative outcomes with commercial potential. Failure is a part of learning and engineering design education needs to understand this when assigning project tasks and assessment rubrics to students. To contextualise this one of the world’s most famous industrial designers come product design engineers 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 and you would ask… ‘Why doesn’t that fail?’ and you can’t find the solution, you can’t think of a solution… there are cleverer people who can, but my view is you can’t, because I’ve got lots of scientists and engineers and they can’t immediately know the answer” (ABC Radio National, 2013). The authors suggest that engineering students should be encouraged to learn from their design process rather than just focusing their final product.

Conclusion

Designing functional, effective (Cropley, 2015), full performing products should undoubtedly be the core purpose of engineering disciplines, however this must not deter creative input. If a product does not meet the functional requirements expected, then there is no benefit of designing it – unless in the rare occasion the aim is not that. However, if some flexibility can be provided to students in a learning context allowing them to think more freely it 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. Therefore, we suggest that the emphasis on creativity needs to be increased in ME design units. In order to do so, open-ended design problems that allow alternative solutions should be encouraged. This will enable students to better experience the iterative design process instead of step-by-step progression that currently dominates the classroom experience. 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. 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 in its entirety.

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 will ensure students do not solely work with a functionality and performance mindset, but also add elements of innovation.

This study is focused predominately on ME, however it is suggested that all types of engineers need to build their creative skills. PDE is fortunate to have this embedded in their program and is something that other engineering disciplines should leverage off. A functional full performing product that meets the needs and desires of the user is clearly of high priority. However, 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.

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