Measuring differing approaches in design between engineering disciplines

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ABSTRACT

Product design is a unique subject offered to engineering students at Swinburne University of Technology. Design and engineering lecturers have collaborated to develop a program that gives greater integration of design into engineering curricula. The subject’s intentions are to develop:

- an understanding of the product design cycle,
- appreciation of design principles in engineering,
- the ability to creatively design quality products for a sustainable environment.

This elective subject available to final year Mechanical Engineering (ME) students, Robotic Engineering (RE) students and Product Design Engineering (PDE) students aims to develop understanding of both the creative and analytical approaches to design.

The diverse student cohort afforded the opportunity for design lecturers to directly compare engineering students from different courses and compare their responses to design tasks. This was of particular interest as some of the students were from the product design engineering course which integrates industrial design and mechanical engineering curricula.

The subject challenges the students through two design projects; one an open-ended or ‘wicked’ problem and the other with a tightly constrained brief. Responses to these briefs differ significantly between the engineering disciplines and this paper highlights the initial findings.

The results of this ongoing comparative evaluation (whilst in its early stages) appear to support the need for greater emphasis on design and creative activity in engineering curricula.

The challenge in teaching an industrial design approach to engineers is promoting creativity in the final year of the students engineering degree. Visual examples of student outcomes demonstrate the benefits, difficulties, revelations and accomplishments of teaching the fundamental elements of design to engineers. These vast differences between students of differing disciplines reinforce the importance/benefits of multi-disciplinary studies and are discussed within this paper.

INTRODUCTION

In this comparative study, the student outcomes from the engineering disciplines involved were compared and evaluated. The comparative evaluation examines the outcomes from two vastly different design exercises; one an open-ended problem and the other, highly constrained.

ME, RE and PDE students are offered an elective Product Design subject, which is in part taught by design lecturers. During this module students gain an understanding of the product design cycle, an appreciation of design principles in engineering and nature, and creatively design products for a sustainable environment. This is the first time that the ME and RE students have been asked to develop a product, rather than a machine or mechanical system. PDE students have worked on projects of this nature from the beginning of their course, making this an interesting evaluation measuring differing approaches in design between engineering disciplines.

Trying to communicate and teach the basic elements of industrial design to an engineering cohort is challenging. The sustained action of doing this over the past four years validates the findings of this paper. To better understand the student’s capabilities a comparative evaluation process was conducted. Students from the three engineering disciplines involved were taught by the same staff to ensure consistency and each student undertook two design challenges: either an open-ended problem or a constrained problem. The projects were distributed randomly to students creating an even spread of both projects.

The projects chosen did not require specific design skills (to ensure that the ME and RE students were not disadvantaged), but do require creative problem solving, application of engineering knowledge and an appreciation of the needs of intended user and environment.

I. TEACHING CHALLENGE

The biggest challenge in teaching an industrial design approach to engineers was the very basic level of design ability of the engineering students—with the exception of the Product Design Engineers who had several years of design training. The difference between a novice and an expert was vast and difficult to manage and students required much
guidance to complete the projects. These differences in competency formed the basis of the comparative study and the creation of the two differing projects to better understand the skill sets of each discipline.

Cross (2004) notes that education in design has well-established practices that are assumed to help the progression from novice to expert; but there is still precious little real understanding of the differences between novice and expert performance in design, and how to help students move from one to the other.

Whilst Cross refers to educating designers rather than engineers, it is applicable to relate the similarities. When considering the cohort of students in this study, a Product Design Engineer within the group could be classed as an expert on design when compared to a Mechanical Engineer or Robotic Engineer who has had no direct design training. The main challenge faced by teaching staff was to balance the curriculum to suit all disciplines involved.

Atman found from an analysis of engineering students that novices (first year students with no design experience), who spent a large proportion of their time defining the problem did not produce quality design. However, with senior students, it was found that attention to ‘problem scoping’ (i.e. adequately setting up the problem before analysis begins) did result in better designs (Atman 1999). It was highlighted in this study that a majority of the first year students simply got stuck in problem-definition and did not progress satisfactorily into further stages of the design process.

This was also the case within the comparative evaluation described in this paper. PDE students could be defined as senior, as they have had design training throughout their degree. ME students and RE students could be classed as junior (first year) as they have had no design training up until this point in their course. The findings from this research reinforced Atman’s findings. ME and RE who are inexperienced at design related activities spent large proportions of time trying to define the problem and failed to advance to a successful design solution. The PDE students, on the other hand, who have experience with design, were better positioned to define the project problem and work through the design process to achieve a successful outcome.

II. PROJECT EXAMPLES

The first project (Project A) was open-ended, requiring students to design a ‘water transporting device’ to be used by people living in remote communities where sources of clean drinking water are distant from the site of the community dwellings. The device must be human powered (preferably by one person), durable with a capacity of 80 litres and must be able to be used through rugged landscapes, in particular across flooded plains, or up and down steep rocky terrain.

A creative approach combined with a user-centred focus, clever use of technology and sound engineering principles was essential for a successful outcome. This unconstrained project required students to demonstrate competency in problem framing, divergent thinking and creativity.

Project B (the constrained project) required students to design a stool or chair that could be made entirely from a single piece of mild steel sheet. The furniture must be capable of supporting the loads applied by a 100kg person, but also lightweight and suitable for an outdoor cafe with storage considerations. Students were challenged to determine appropriate strength versus weight, explore manufacturing capabilities (folding, stamping, pressing, rolling, crimping etc.) and explore three-dimensional forms to achieve structural strength. This heavily constrained project relies less on big picture conceptualisation (as does project A), but rather on the application of materials and manufacturing knowledge combined with structural engineering principles to achieve a user and environment focused outcome.

A consistent assessment criterion was created that encompassed both projects to ensure no bias towards any particular project. Students were assessed against the following criteria:

Constrained project
- Students lacked an understanding of metal forming processes/potential forms; however some basic engineering principles (structural triangulation) emerged.
- Forms involved simple folding processes only – no pressing, rolling etc.

Open-ended project:
- Students struggled to define the problem
- Students fixated on existing Roller solutions
- Lack of consideration for environment (steep terrain).
- One good example of user consideration (design allowing empty drums to be carried stacked on head) – by a PDE student.

Fig.1. The weakest outcome for the open-ended problem was submitted by a ME student. The solution clearly indicates fixation on prior solutions (the well known Hippo Roller).
The strongest outcome for the open-ended problem was submitted by a POE student. It shows a high level of user consideration in regard to filling, pouring and transportation.

The examples shown above are representative of differences found between engineering disciplines when dealing with a design project. The weakest outcome from ME is used in the first project example (Fig. 1) comparing this to the strongest outcome from PDE for the same project (Fig. 2). All ME and RE project outcomes for the open-ended problem were poor in comparison to the PDE outcomes. This showed that ME and RE students struggled with problem framing when the final solution was 'not immediately apparent.

Apart from the fact that PDE students are taught the necessary computer programs throughout their course to be able to create appealing product visuals, the focus on these outcomes was the design solution. Assessment in these projects was a challenge as the PDE outcomes were always visually well resolved and presented when compared with ME and RE outcomes and it was necessary to look past the appealing visuals to focus on the design. In the open-ended project the final design solution is similar. Project solutions were essentially rotating barrel that is pushed or pulled by a human, influenced greatly by an existing product, the Hippo Roller. Whilst this was a common solution for all students, the PDE students further enhanced this approach with greater consideration of user needs and safety, including brakes, provision for the transportation of empty containers, and ease of filling and pouring. The training PDE students have throughout their course gave them the ability to think through the design process and they were better positioned to more clearly define the project problem and create a successful design outcome. Detailed design solutions from the PDE outcome show a higher level of comprehension. Fig. 2 shows two separate barrels which makes the device easier to operate and easier to fill with water. The human figure and background image contextualises the design and gives a clearer sense of how it functions. The material connection between the handle could be used as a storage/transportation device. These observations are purely taken from the final outcome – design innovations that are not evident in the ME example (Fig. 1).

Fig. 3 and 4 display the strongest RE outcome compared with the weakest PDE outcome. This is done to show a non-bias account when comparing the final project outcomes.

Both presentations effectively communicate the design aesthetic, the manufacturing sequences and the intended demographic (seen within the text). The aesthetics in Fig. 3 lack creativity and were justified by the engineering detail that was developed for the project. At no stage did any ME or RE student explore curvaceous shapes to create an original styling outcome or generate structural strength. Figures 3 and 4 demonstrate that with a constrained problem, all of the represented engineering disciplines are capable of achieving a satisfactory result. It is the open-ended problem that clearly differentiates the creative minds of PDE students compared with the analytical minds of ME and RE students.

Obviously there were a lot more projects to choose from but the examples shown are good evidence of what was observed. They highlight the similarities and differences that exist among engineering disciplines when dealing with design problems.

Fig. 3. The strongest outcome from a RE student for the constrained problem. Technically competent and well detailed.

Fig. 4. The weakest outcome from a PDE student for the constrained problem. The design demonstrates use of curvature for strength and styling and a solution appropriate for the intended environment.
III. PROJECT ANALYSIS

The difference in approach and outcomes were measured and evaluated in several ways to provide a succinct evaluation used as evidence in this study. This included simultaneous observation and note taking, conversation with students at all stages during the project, an anonymous retrospective survey at the conclusion of the project, and examination of student outcomes – interim sketches and final design outcomes.

Design outcomes were evaluated by lecturing staff against the criteria outlined in the project briefs. The important criteria for evaluation were as follows:

- Application of engineering knowledge to a real-world outcome.
- Demonstrated understanding and addressing of user needs.
- Appropriateness of solution to user and environment.
- Technical resolution of final design – manufacturability, uses of materials etc.
- Ability to broadly conceptualise and not fixate on prior solutions (project A).

To gain a better perspective from a student’s point of view a survey was conducted at the end of the subject. Students were also examined to identify their levels of comfort with either the open-ended or constrained problems, examine the impact of their sketching abilities and evaluate the overall process. This clarified some of the initial thoughts given to this subject, but also provided unexpected findings. The main findings from the surveys are:

- ME students and RE students were satisfied with their ability to communicate their thoughts and designs – this however was not evident in the submitted work.
- Results were better than expected (especially on the constrained project), even though this was new territory for many ME and RE students. This may be due to one-on-one consultation and mentoring by the design lecturers during the project.
- All ME and RE students noted in surveys that they were not comfortable with short lead times.
- ME and RE students stated they were more comfortable with constrained problems (which met expectations).
- All students felt challenged by the projects but felt that the problems posed suited their skill set and wanted more solution-focused projects in their course.
- The ME and RE students showed enthusiasm and a high level of engagement throughout the project. For many students this was the first time they had the opportunity to engage with design and the overwhelming response was they enjoyed this type of project. However, it must be noted that it was difficult to promote creative thinking to ME and RE students.

IV. ANALYSIS: CONSTRAINED PROJECT

This analysis separates the ME and RE students with the PDE students to clearly show the differences identified between a typical engineer (ME and RE) and a design engineer (PDE).

ME and RE students:

- Utilised simple folds only – no complex processes.
- 75 per cent of the designs were folded cube shapes – visually unrefined and driven purely by functional requirements.
- Designs were more refined with better structure and processes than on the open-ended project.
- All designs were significantly more successful than on open-ended project.

PDE students:

- More comfortable with complex 3D forms, materials and processes and they were willing to ‘push’ the manufacturing processes further.
- Use of curvature for strength and aesthetics was well resolved.
- Final designs were more aesthetically pleasing and had clever stacking solutions.
- Final designs were more technically proficient and considered material waste minimisation – including sheet cutting patterns.

V. ANALYSIS: OPEN-ENDED PROJECT

ME and RE students:

- All projects were poorly resolved - 50 per cent were very bad.
- Designs lacked user consideration – filling water, user control, etc.
- User safety was not considered: braking, steering etc.
- All designs lacked innovation – there were no original solutions – evidence of ‘fixation’ on existing solutions usually found on the Internet.
- All designs were quite similar solutions (water filled rolling device).
- All designs lacked technical detail.
- Not one student considered the ‘transport over flooded landscape’ scenario.

PDE students:

- More flexible solutions, e.g. consideration of transportation of empty units.
- 50 per cent of designs were multi-functional – capable of floating in water and being rolled or carried.
- Significantly more technical manufacturing resolution and attention to detail design.
- All PDE students considered/resolved braking systems (for hill ascent and descent).
- Filling systems were considered – ease of filling.

Summary of findings for both projects:

- Constrained project had similar results – all students had a successful outcome.
• ME and RE students appeared out of their depth with the open-ended project – the students struggled with framing the problem/solution.
• PDE students excelled at the open-ended problem – solutions were creative, unique and very well resolved.
• PDE students were much better communicating the visual intent of their design (as expected).

CONCLUSION

The projects facilitated a process that measured the differences between abilities and approaches of final year students when confronted with a realistic problem that required a creative product solution. It was anticipated that the PDE students would perform better at the open-ended design challenge and would demonstrate a more creative and user-centred approach to the problem. The results supported the argument that exposure to sketching and design, project based learning and application of science to practice early in the curriculum leads to a more creative and adaptive design engineer.

It was anticipated that the constrained problem would not necessarily favour either discipline, with results being useful in comparative reviews of teaching pedagogy and real-world learning. However the PDE students excelled at the constrained project as well, considering user needs, environment and aesthetics and better utilising the strengths of the chosen material.

The nature of teaching industrial design processes to engineering students uncovered additional questions and areas of inquiry. The design process is not linear allowing for overlap and time for iterations. Zimmerman (2003) describes the iterative design process as a methodology based on a cyclic process of prototyping, testing, analysing and refining a work in progress. In iterative design, interaction with the designed system is used as a form of research for informing and evolving a project as successful versions or iterations of the design are implemented.

Fig. 5. The iterative design process typically adapted by PDE students.

Fig. 6. The linear engineering process typically adapted by ME and RE students.

This iterative process is hard for a ME and RE student to comprehend as they are mostly familiar with linear processes where a definitive answer is usually found. To apply the creative side of the brain to a open-ended problem caused difficulties for the ME and RE students. The PDE students on who have been trained to use both creative and analytical approaches were much more comfortable with the project challenges.

Whilst it is common for ME graduates to be engaged professionally in relatively constrained activities, it is apparent that exposure to open-ended problems and creative design has benefit in all areas of engineering activity. Engineers need to be comfortable with the unexpected or unintentional and balance strong technical engineering science with the creative and adaptable approach of the designer to achieve successful design solutions.

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REFERENCES