AN INTEGRATED APPROACH FOR THE TEACHING OF MECHANICS AND ELECTRONICS IN A DESIGN CONTEXT

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ABSTRACT
This paper examines the traditional engineering-based provision delivered to Product Design and Technology (BSc) undergraduates at the Loughborough Design School and questions it relevancy against the increasing expectations of industry. The paper reviews final year design project to understand the transference of engineering-based knowledge into design practice and highlights areas of opportunity for improved teaching and learning. The paper discusses the development and implementation of an integrated approach to the teaching of Mechanics and Electronics that formalises and reinforces the key learning process of transference within the design context. The paper concludes with observations from the delivery of this integrated teaching and offers insights from student and academic perspectives for the further improvement of engineering-based teaching and learning in a design context.

Keywords: Design education, product design, engineering design, mechanics, electronics

1 INTRODUCTION

In the current economic climate, Design and Engineering graduates employed for the creation of modern products for global markets face significant challenges. They are increasingly expected to achieve higher levels of product maturity at launch, where previously this was only achieved and/or expected after several years of exposure to the market [1]. Increasing expectation means that graduates of both disciplines must be technologically practised, creative and solution-focussed with a strong technical knowledge-base, understanding of human-centred design and an ability to work in multidisciplinary contexts [2]. These desirable qualities are an interesting mix of attributes traditionally associated with Industrial Design, Mechanical Engineering and Electrical Engineering graduates [3] resulting in an education shift towards Product Design as an academic subject.

Product design as an academic subject has resulted in two distinct educational approaches, the Engineering response and the Design response. Both approaches share common goals and expected attributes of their graduates; however, the two traditionally disparate fields differ in their pedagogical practice.

Traditional engineering pedagogy can be described as narrow and deep, with students often being taught isolated subjects using linear progression model [4]. In contrast, the design pedagogy can be described as broad and deepening, using a holistic approach, students are exposed to an entire range of subjects from the beginning of their studies. As they progress through each level of the programme, each subject is delivered in more comprehensive depth, building on the previous knowledge base and promoting students to practice and develop their integrative skills. A further aspect of design-based pedagogy is the continual adoption of Problem-Based Learning (PBL) which addresses a key issue in the cognitive sciences of transference - defined as the ability to extend what has been learned in a particular context to other, new contexts, further reinforcing integrative skills [5]. A defining feature of product design-based programmes is the use of Final Year Design Projects (FYDP). Normally a significant credit bearing module, the FYDP module is the culmination of all previous design education and provides the students with the opportunity to apply and practise their product design skills in an academic context. All design education within the programmes is driven to this aim and it is here where students' integrative skills and ability to implement transference is academically assessed.

2 DEVELOPING ENGINEERING-BASED CURRICULAR IN A DESIGN CONTEXT

The changing expectations of industry have been a consistent motivating factor for the continual development of all curricular within the Loughborough Design School. During the previous two academic years the engineering-based teaching (Mechanics and Electronics) have received a significant redevelopment of their curriculum. Driven by the changing needs of potential employers, a review was undertaken to understand the current state of engineering-based teaching within the BSc Product Design and Technology (PDT) programme to highlight potential improvements in both teaching and learning.

2.1 Engineering-based curriculum review

Using a top-down approach, key academic staff were tasked with developing a list of desirable, industrially relevant engineering-related attributes that graduating PDT students should possess. These attributes were then mapped against current learning outcomes of existing engineering-based modules to highlight areas of opportunity. Student feedback and consultations through appreciative enquiry techniques were used to determine specific issues and drive discussions. Finally, anecdotal evidence was collated from observations of FYDP outcomes. The desirable engineering-related attributes, in no significant order, can be summarised as:

- Strong/broad technical knowledgebase
- Technologically Innovative/creative and pragmatic
- Technologically practised/assured
- Problem defining and solution-focussed
- Analytical and evaluative
- Multifaceted/Multidisciplinary
- Collaborative/team orientated

Outcomes of this process revealed that while the levels of Mechanics and Electronics education was appropriate and timely, providing a broad technical knowledge base, student satisfaction was low. It was noted that while PDT students recognised (mostly) the value of the engineering-based education delivered, their desire for greater levels of applied-learning was high. Observations of physical product outcomes from the FYDP module demonstrated a general trend of significant engineering-based learning application. However, it also demonstrated weak mechanical design and functionality execution through the inappropriate use of engineering knowledge. These aspects were echoed in electronic design, where limited integration of embedded systems and a significant reliance on bread-boarding activities for electronic circuits in functional prototypes was also recorded. These observations suggested that practical transference from the engineering-based subjects to design-based subjects was low and supported students' desires for greater levels of applied-learning. The findings were related back to the desirable engineering-related attributes and while evidence was found supporting all their current existence, evidence supporting certain attributes was far less prevalent. These included:

- Technologically practised/assured
- Technologically Innovative/creative and pragmatic
- Analytical and evaluative
- Collaborative/team orientated

These attributes highlighted a significant opportunity to improve the current teaching and learning of engineering-based subjects through the introduction of applied learning in a PBL environment. To achieve this it was decided to incorporate the design context directly into the engineering-based curricular utilising a design project vehicle. Instead of relying almost exclusively on the students' ability to contextualise and transfer engineering-based knowledge into design practice, this approach would help formalise and reinforce this key learning process.

3 MECHANICS AND ELECTRONICS INTEGRATED DESIGN PROJECT

The core educational aim of the project was to provide final year students with a richer, applied learning experience through the design of a physical and functional outcome requiring the significant

application of engineering-based knowledge. The benefits of physical models and working prototypes as a vehicle for teaching and learning are well documented [6]. They are an essential tool in developing judgement via critical evaluation and reflection, and provide students with the opportunity to apply and reinforce their acquired knowledge in a design context [1].
Providing students with the opportunity to engage in a multidisciplinary, integrated design project also required an integrated approach to the educational delivery of both the Mechanics and Electronics modules. This was achieved by developing a project vehicle that required the same final outcome but enabled the attainment of subject specific objectives that could be academically assessed. Integrating the project work for both engineering modules (Mechanics and Electronics) enabled a joint project brief to be established that required students to work on parallel, supporting activities. Students were provided subject specific lecture content relevant to project objectives, independently, and supported with dedicated laboratory sessions and weekly tutorials as appropriate. This process allowed an ambitious 'design & make' project vehicle to be utilised that directly addressed the issues of transference and applied learning.

3.1 Learning outcomes

The learning outcomes of the integrated project were developed to reflect the educational aims and opportunities observed from FYDP outcomes. The learning outcomes combined both engineering subjects and reinforced their purpose in the design process through application. All learning outcomes are summarised in Table 1.

Table 1. Integrated project learning outcomes

Knowledge and Understanding (KU)	
KU 1	Mechanical design theory and design of machine elements
KU 2	Design issues in programmable and embedded electronic control
KU 3	Design of Electrical machines including printed circuit board design and manufacture
Intellectual/Cognitive skills (ICS)	
ICS 1	Apply scientific principles in the modelling and analysis of mechanical and electronic systems
ICS 2	Apply investigative skills to understand and evaluate performance of devices, systems and products
ICS 3	Apply mechanical and electronic design competencies to evaluate and generate design criteria related to the performance and safety of products
ICS 4	Apply technical reporting skills on the performance and safety of products
Practical/Specific skills (PSS)	
PSS 1	Design, prototype, test and evaluate mechanical/electronic control systems to meet a required product specification
PSS 2	Apply laboratory equipment to produce data and quantify performance parameters for mechanical/electronic devices, systems and products
PSS 3	Apply IT resources for modelling and design of mechanical/electronic systems
Key/Transferable skills (KTS)	
KTS 1	Source, evaluate and manage information from a variety of sources
KTS 2	Use scientific based methods in the solution of technical/physical problems
KTS 3	Use creativity and innovation in problem solving technical/physical problems
KTS 4	Interact effectively with others, working as a member of a small team to set goals, manage workloads and meet deadlines
KTS 5	Articulate ideas and information comprehensively in visual, oral and written forms
KTS 6	Articulate reasoned arguments through reflection, review and evaluation
KTS 7	Apply skills in information technology in presenting data and reports

3.2 The project vehicle: Electro-mechanical can crushing competition

Finalising a suitable brief that allowed students to attain the proposed learning outcomes was a difficult task. Many potential devices/products were proposed and judged on their complexity, attainability, likely duration (design and build time) and overall suitability. It was therefore decided to establish a project brief for an electro-mechanical can crushing device. This project vehicle allowed

the extensive application of mechanical design while also requiring an intelligent embedded control system through the significant application of electronic design.
Working in teams of three, each team had a total of 13 weeks to design, fabricate and evaluate an electro-mechanical drinks can crushing device. The students were asked to develop initial concepts, undertake a full mechanical and electronic analysis, detailed design, fabrication, and a final evaluation of the device and team performance. To promote motivation within the module cohort and introduce an element of fun, the project was run as a competition. The aim of the competition was to successfully crush five individual cans in the fastest possible time. While the competition was not a directly assessed component it was a key indicator for the successful attainment of learning outcomes and a significant vehicle for critical reflection and evaluation.

4 PROJECT OBSERVATIONS AND DICUSSION

Throughout the project, dedicated weekly tutorials with the individual teams were scheduled. During these tutorials, evaluative feedback was provided to the teams on their direction, progress and likely attainment. These discussions helped steer the projects and reinforce the learning and application of engineering-knowledge in the design process. The tutorials were also used to record observations on the delivery of the project, its fundamental appropriateness and the issues experienced by the students. The key outcomes of this process are discussed for each phase of the project.

4.1 Project initialisation – Week one to three

The first three weeks of the project were well received and the students demonstrated a keen motivation for the project, relishing the opportunity to engage in the design process. Using a variety of web resources all teams collated existing solutions, investigating their potential for improvement and inclusion in their designs. Each team also developed a vast amount of potential solutions and concept ideas to meet the fundamental requirements of the project. Parallel activities for quantifying the crushing force required was also viewed as a fun activity and students happily engaged in scientific based investigations to determine this key result.
Sequential activities for developing a team specific PDS were less well received and resulted in some teams questioning its value. However, all teams were reminded of the design process and the need to develop a list of key criteria to allow the generation of suitable concept designs. They were also reminded of the requirement to evaluate their design decisions and outcomes, and the value of the PDS as a vehicle for this activity. This evaluative and instructional feedback motivated the teams and resulted in the production of detailed and suitable PDS documents. The final activity of the initial phase involved concept generation and the direct application of the design process. All students readily engaged in this activity using a variety of design techniques including sketching, sketch modelling and CAD work. A significant proportion of the cohort utilised virtual prototyping techniques to produce animated CAD models to verify their decisions and demonstrate their intended functionality. The appropriate use of CAD also resulted in the production of high-quality rendered images of their final concept design.

4.2 Project analysis – Weeks four to six

The second phase of the project was the vehicle for the majority of engineering-based knowledge and learning application. Here the students embarked on applying their previously acquired engineering-based knowledge to the design process. In contrast to the previous three weeks of project, this period involved a separation of mechanical and electronic-based activities as follows.

4.2.1 Mechanical design analysis

Working both collaboratively and individually, each team member was responsible for the production of a full mechanical analysis of their concept design. This activity required the student to utilise a range of mechanical science topics to calculate expected loads, resulting stresses and appropriate material dimensions to ensure their final detailed design was mechanically viable.
Observations from the weekly tutorials revealed that students were again motivated for this activity but also found the process difficult. Reoccurring comments revealed that while they understood (mostly) the theory of the mechanical science topics being utilised they struggled to actually apply these concepts into the design process for the generation of a physical fully-functional artefact. Here the students were removed from the comfort-zone of working theoretically using typical calculation-

based questions or laboratory activities with model answers. Students experienced uncertainty and expressed concerns that they were overwhelmed by the potential enormity of the task and failed to recognise where they should start or how to correctly apply their engineering knowledge.

Evaluative feedback was again used to steer their analysis and demonstrate the appropriate use of mechanical science. Using individual consultations, students were directed to exam aspects of the concept and relate these directly to standard cases for static and dynamic loading conditions. This process helped remove some of their uncertainty and reengaged them in this key applied learning activity. Eventually students began to fully recognise the importance of the prior theoretical learning and understood how this was directly relevant to the design process. This was an important outcome of the project and allowed students to apply their prior learning in a true design context.

4.2.2 PCB generation

Mirroring the concerns and difficulties experienced in the mechanical analysis, teams also struggled with the application of electronic-based knowledge and learning in the design of their embedded, intelligent control system. Working collaboratively, each team was responsible for developing their electronic functionality and specifying key measurands. Again students commented that they were overwhelmed by the task, removed from their comfort-zone they experienced uncertainty through the lack of model answers and results. Using individual team tutorials, the students were directed to exam their specified electronic requirements and relate these to prior learning activities for potential solutions. Segregating tasks allowed the teams to sequentially address specific requirements and enabled the final development of the integrated functionality. Teams began to engage in flowcharting their program operation and description of their user interface. Parallel breadboard activities were also used to test their circuit operations before developing schematics for a final PCB design. This was another important outcome of the project and allowed students to apply their prior learning in a true design context.

4.3 Project fabrication and testing – Weeks seven to twelve

The third phase of the project involved the fabrication and realisation of their crushing devices. Here the teams were responsible for translating their applied theoretical work into fully-functional physical artefacts. Feedback from the students again showed that they were highly motivated by this activity and relished the opportunity to apply their theoretical work to a physical outcome. However, teams quickly began experiencing difficulties in the translation from theoretical to actual through a lack of practical fabrication or workshop experience/skills. Team consultations revealed a level of practical fabrication skills developed from previous prototyping activities existed. However, these were limited and this was (potentially) the first instance where students were required to produce a fully-functional device. All previous prototyping activities had concentrated on form and finish only rather than true functionality through mechanical design.

This step change in emphasis required the students to be more meticulous with their planning and deliberate with their execution, resulting in a much longer fabrication period than they had initially anticipated. Weekly team tutorials were used to direct this process and provide practical advice on the fabrication of machine elements. As a consequence, a significant number of teams re-examined their chosen design and re-engaged in CAD modelling to finalise their designs completely. The second generation CAD models were far more detailed and included significant manufacturing details that previously had been ignored. The CAD models were used to generate technical drawings of required components that were then fabricated to the required tolerance.

In parallel, teams were fabricating their final PCB, generating their final program code and considering the integration of their embedded control system into the crushing device. This was another significant task and again feedback revealed considerable difficulties. Students commented that while they were confident producing isolated functionality they were sceptical of successfully integrating both mechanical and electronic elements. Weekly team tutorials were again used to direct this process and provide practical advice to deliver this key requirement.

The physical prototyping aspects of this project were a crucial learning activity and provided the students with a vehicle for the evaluation of design decisions and an opportunity to be technologically practised. Students were able to reflect more easily on the decision they took and directly evaluate their outcomes. Feedback from the students indicated that was an extremely beneficial activity and provided them with practical experience that could be applied in related areas of their FYDP.

4.4 Project evaluation and final submission – Week thirteen

The final phase of the project involved the competition, evaluation and final submissions. The competition was not a directly assessed component but provided the teams with a key indication for the success of their design decisions and a vehicle for reflection and evaluation. It also provided students with the opportunity to examine and evaluate alternative design decision made by competitive teams and further increase their technical knowledgebase.

The reflection and evaluation was a crucial aspect of the project as it allowed the students to reinforce their learning and translate best practice to subsequent design projects (FYDP) via technological experience. The reflection and evaluation was recorded in two assessed components, the final team presentation and report. The presentations allowed the teams to summaries their project and evaluate the key aspects to the entire cohort – this provided all teams with the opportunity to assimilate potential issues and elements of best practice. The written evaluation was delivered in greater detail and provided the teams with a further opportunity to reflect more deeply on their design decisions and construct these into reasoned arguments suggesting potential improvements for further work.

5 CONCLUSIONS

Traditional design pedagogy is delivered almost exclusively through applied learning using PBL activities. In contrast engineering-based subjects are often delivered to design students using a traditional lecture-based approach. A review of this approach indicated a potential consequence for low transference to the design process. By supplementing the traditional lecture-based approach with an integrated 'design and make' project vehicle, requiring the extensive application of engineering-base knowledge, the key cognitive learning process of transference can be formally addressed and provide Product Design students with a richer and more beneficial learning experience that more adequately prepares them for the expectations of industry and employment .

Unstructured interviews and appreciative inquiry techniques where used with students post-project to understand their perception of the project and revealed some interesting insights. Students really appreciated the opportunity to apply both Mechanics and Electronics-based learning in a single design project but found the project very technically and time demanding. Reoccurring comments included:

- *"I've learnt more in this project (about Mechanics and Electronics) than the previous two years of study"*
- *"Applying Mechanics and Electronics to a real-world design problem really helped me better understand the subjects"*
- *"Actually building something that works was a real challenge but will really help my FYDP project"*
- *"Why don't we have more projects like this"*

While the comments received are subjective and can only be treated as anecdotal evidence at best, they do suggest the project provides intrinsic educational value and a suitable approach for combining the design context directly into engineering-based pedagogy.

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