THE MISSING LINK: CO-CREATION THROUGH DESIGN ENGINEERING PROJECTS

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ABSTRACT
The Design Project units are the cornerstone of academic and professional development within the undergraduate Design Engineering programme at Bournemouth University. They provide technical, conceptual and theoretical challenges to be resolved through the integration of taught elements and self-directed learning to yield tangible outcomes. Final year students supplement their project through the Advanced Technology and Innovation unit. Here they work in conjunction with the research centres to develop understanding of a specialised discipline and write a research paper. However, students have limited time to develop before formulating a methodology while access to research facilities is limited and the learning curve for research equipment can be time consuming.
To address these issues, 2nd year students were asked to design a fatigue testing machine for use within the Sustainable Design Research Centre as a design project. Designing such a device provided students with a sound understanding of fracture mechanics at the beginning of the project, operation capability of test equipment, test methodologies and systems control; essentially they developed the prerequisite knowledge to engage in their 4th year research. Funding was secured from the University's fusion investment fund (co-creation strand) to provide flexible adaptable elements and construct a pair of exemplar fatigue testing machines reflecting those developed by the students. The familiarity through the inbuilt adaptability of mechanism, control and data acquisition systems allows for a rapid understanding of their operation and capability hence short learning curve with equipment prioritised for undergraduate research.

Keywords: Co-Creation, Projects, PBL

1 INTRODUCTION

In recent years, there has been a drive to integrate Research, Professional Practice and Education within our university's schools, research centres and teaching frameworks. More recently the process has been formalised through the development of the "Fusion" concept and is a central feature of the university's 2018 strategic plan [1]. The importance of the fusion concept to the university can be identified by conducting a frequency search of keywords and their derivatives within the strategic plan (Table 1) and yields insight to the university's general direction.

Table 1. Bournemouth University Strategic Plan, Keyword Frequency

Keyword and Derivatives	Frequency
Research	93
Fusion	77
Learning	45
International	39
Practice	36
Business	29
Enterprise	5
Teaching	4
Global	4

Within the context of the strategic plan, fusion is described as *"the combination of inspirational teaching, world-class research and the latest thinking in the professions which creates a continuous and fruitful exchange of knowledge that stimulates new ideas, learning and thought leadership"*. To reinforce this goal a Fusion Investment Fund is available and specifically designed to encourage the fusion of learning, research and professional practice through three specific strands; co-creation & co-production, staff mobility & networking, study leave [2]. For the Design Engineering programme, there has been consistent application of the Fusion concept through the Design Projects units at Year 1, 2 and 4. These have been predominantly related to niche design projects with community partners such as Poole Tidal Energy Partnership and the Bovington Tank Museum.

1.1 Design Engineering Projects

Design Project units are the cornerstone of academic and professional development for undergraduate Design Engineering programme students; These represent 20 ECTS credits at Year 1 & 2 and 30 ECTS credits at year 4. Students develop a solution to a project brief encompassing the design process described in BS8887 [3] and BS7000 [4] amongst others and meet the requirements of the Engineering Council's EC^{UK} SPEC for accredited degree programmes [5]. The Project units provide technical, conceptual and theoretical challenges to be resolved through the integration of taught elements and self-directed learning to yield tangible outcomes. They also present an opportunity to develop relationships with commercial, industrial and community partners and can act as a test bed for new conceptual models and alternative learning methodologies [6-8]. For second year undergraduate students there are two primary projects, the first is typically a small mass produced product representing 35% of the unit with the second a larger niche project representing 45%. For final year students, the project is represented by a single work and complemented by the Advanced Technology and Innovation (ATI) unit; here students develop a deeper understanding of a specialised engineering discipline leading to a research paper.

Reviewing the performance of the 2nd year project unit and the 4th year ATI unit identified four key issues within the programme:

1. Students often perceive their 2nd year projects as academic exercises where outcomes have no relevance to their final year studies.
2. Final year students are time constrained to develop a deep understanding of their chosen discipline before formulation of methodology for their ATI research.
3. The learning curve for successful operation of specialised research equipment can be time consuming and operator error costly.
4. The use of research facilities is limited due to prioritization of access.

These four factors combine to make access to equipment for short duration projects unlikely with little opportunity for undergraduate use.

2 LINKING DESIGN PROJECTS TO RESEARCH

The issues identified within the ATI unit could be overcome by allowing the students to develop the pre-requisite knowledge and understanding at an earlier stage in their academic career, before they commence their final year. The problem is identifying space in the academic calendar to ensure adequate understanding of the technical field and methodologies alongside prioritized access to specialized equipment. The issue identified within the 2nd year projects, relevance to final year studies, can be addressed to simultaneously solve those issues identified within ATI by providing a design project where understanding of research methods is central to success. It is clear from experience that students develop an intrinsic interest in subject matter related to the design work they conduct, essentially forming an emotional bond with their product [7]. Harnessing these elements they adopt self-directed learning to acquire the pre-requisite knowledge required to successfully complete their projects, an essential skill they will require to develop as competent design engineers in the future. By designing research equipment, students will need to acquire knowledge specific to that research domain and the outcomes dependent upon that understanding. Pasman and Boess [9] explored the value of designing for research within the context of design students noting *"…making things for design is something design students and are experienced with, using it for in a research context could catalyze their interest in design research."* However, this is countered by Dowlen [10] who argues that *"We need to accept that designers being academic researchers does not work, in general. And student designers work even less well as researchers."* Although this may be the general case for "design" students, it can be argued that Design Engineering students can benefit from exposure to the experimental and bespoke nature of research with regard to their future roles as innovators or research and development engineers.

2.1 Project brief

To achieve the goals outlined above 30 Design Engineering students were asked to design a one-off test machine for conducting fatigue analysis in a cantilever configuration. Sample size was breadth: 5mm, depth 10mm, effective length 250mm and notched at midpoint to a depth of 2.5mm complying to the relevant standard [11]. Sample material constraints were not provided and students were therefore expected to design to suit a range of material types based upon available data.

2.2 Project rationale

The design process can vary with methodology adaptation to reflect project complexity, size, volume and value with both iterative and linear models [12]. However, the underlying process is essentially the same and described in general terms in BS8887 [3] adapted by the authors (Figure 1).

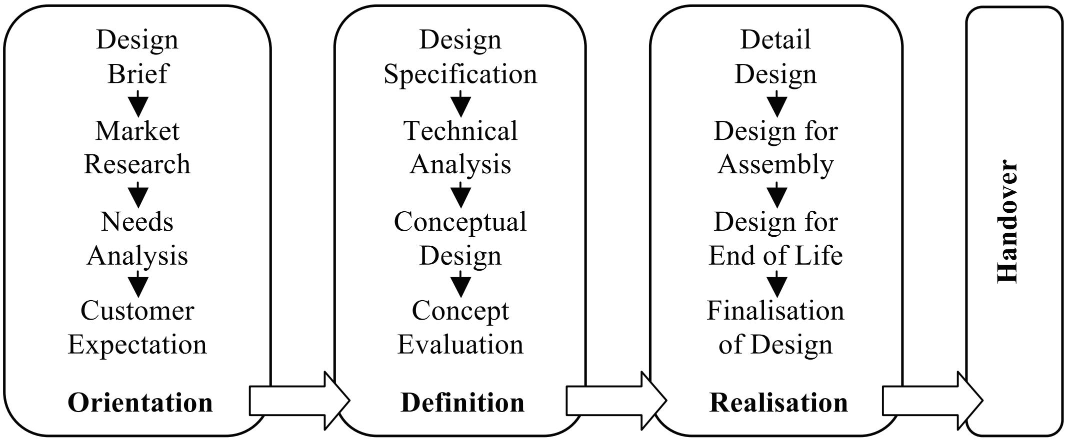

Figure 1. The Design Process, adapted from [3]

Working within the design process it is clear that students must first understand the market and conduct needs analysis to identify key design constraints for the product design specification (PDS). It is this translation process, from general terms within the orientation phase to the SI units of design specification, where the designer requires knowledge and understanding of the scientific principles. In the case of this project, they needed to develop an understanding of fatigue in order to predict key drivers within the PDS.

2.3 Design Specification Derivation

Students were provided a range of material specifications and many supplemented this with their own research. From these materials students identified the maximum load that the sample could support by deriving the maximum stress from the fracture toughness. Students then applied incremental test case loads to the material specification using the Paris equation to derive the number of cycles to failure [13]. By modelling the test specimen they were also able to predict a range of deflections for applied load case, hence system stroke length. Finally, by combining load and stroke they could derive energy and, in combination with operating frequency, power requirement (figure or flow chart showing the flow of information between equations and show a general spec). Typically, students identified the device should provide a maximum force of 1000N, maximum stroke of 40mm and operating frequency of at least 1Hz.

Students recognised that the operational function of the device would, in essence, be the reverse of the methodology for deriving the specification. In other words, the calculated design specifications would be the principle measurements to provide control, data acquisition, or both.

3 STUDENT DESIGN OUTPUT

Most students successfully completed the design project and identified key operational characteristics. At the conceptual stage students typically identified three to four potential working solutions before formally optimizing their final design. Solutions varied between students at both stages but can be grouped by technology both within the load application, measurement and control systems (Table 2). Examining the output there is a clear demarcation between rotary to linear drive systems requiring cams or cranks, whether directly or indirectly and solutions with loaded actuator based solutions. In the case of direct loading the cam or crank displacement translates directly to the sample. For indirect action solutions, the load would typically be applied with weights and the mechanism used to cycle this loading.

Table 2. Technology Categorisation for Conceptual and Final Design

		Design			Final Controls/DAQ						
	Technology	Concepts	Final	Viable	Load-cell	PLC	PC	DataLogger	Camera	Adaptable	Notes
Direct	Cam	11	2	0							
	Crank	11	2	0			1				
	Scotch Yoke	5	-	-							
	Swash Plate	1	-	-							
	Cable	3	2	0	1		1				
	Any Direct	15	6	0							
Indirect	Cam	20	4	4			2	1		1	PIC, Strain Gauges
	Crank	12	1	1				1			
	Scotch Yoke	3	-	-							
	Swash Plate	1	1	1							
	Any Indirect	23	6	6							
Actuator	Pneumatic	21	11	8	10	4	2	1	2	5	Thermo-elastic Analysis
	Hydraulic	12	5	5						2	
	Linear Actuator	4	1	0							
	Solenoid	3	1	1							
	Any Actuator	26	18	14							

From the 30 students 26 proposed concepts with Actuators, 15 proposed directly acting motor driven concepts, 23 showed concepts indirect action while 29 proposed at least 1 direct/indirect solution. For the final design 18 students went forward with actuator based systems, the majority being pneumatic. 12 students chose to proceed with mechanical systems, of which only the indirectly loaded systems were adjudged viable. Within the context of control and data acquisition the most popular solutions were to use a PLC, PC or Data logger. Some students also proposed the use of infra-red imaging cameras to monitor strain through thermo-elastic analysis while others identified the benefits of flexibility that could be afforded by the use of adaptable T-slots within the structural elements. Examples of student work (Figure 2) show the typical general arrangement for the most popular configurations from which all except one student had proposed as a concept or final design.

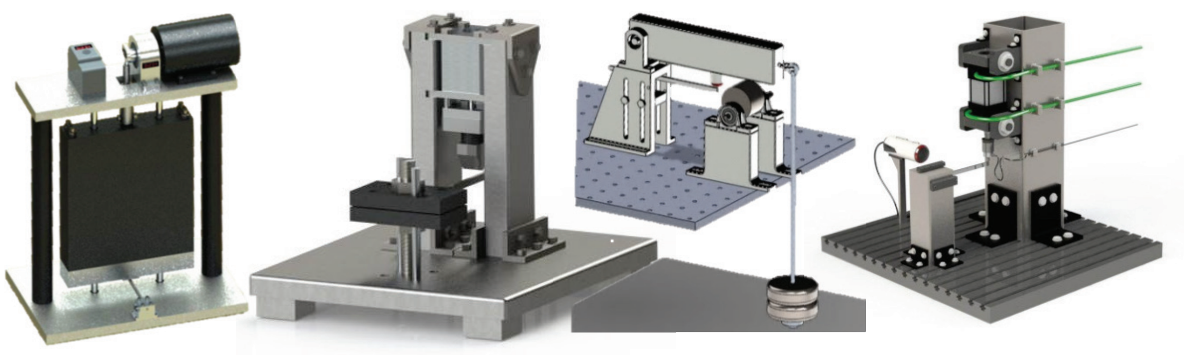

Figure 2. Student Final Designs, L-R: Indirect with Counter, Pneumatic, Indirect with Adaptable Base, Pneumatic with Adaptable Base & I.R. Camera

3.1 Project Learning Outcomes

Student learning within the project was achieved through self-directed PBL methods supported by key tutorials focused upon specific technical knowledge building. By channelling the project through specific technical discipline (Fatigue) students have built up a sound underpinning body of knowledge and experience of practical application. They now have a fundamental understanding of the practical limitations to the technologies explored; from a mechatronic perspective in the application of loading to the logical elements of process control systems and data acquisition. In addition, students have built an intimate foundation to the specifics needs of practical engineering research and how experimental apparatus can be derived from the goals of the research project.

4 LINKING TO FINAL YEAR RESEARCH

The fundamental issues hindering successful final year research work have been identified in the four factors described above. In the case of the factors 1-3 (Perceive relevance of 2nd year projects to final year, time to understand discipline, learning curve for specialised research equipment) these have been overcome through the design project outlined above. To satisfy the fourth factor (prioritization of access to research equipment) funding was secured from the universities Fusion Investment Fund to provide students with access to their own equipment.

4.1 Equipment Specification

Rather than purchasing or constructing a specific fatigue testing machine it was decided to develop a set of configurable building blocks, or adaptable elements, that allow the students to rapidly construct equipment that reflects their own design and the methodologies they wish to employ. Examining the student proposals it was clear that two basic designs should be configurable (indirect loading and pneumatic) thereby encompassing the Conceptual designs of all of the students and the majority of their final designs. The kit comprises various components (slotted structural elements, pneumatic cylinder, loadcell, control valve, motor, eccentric, pulleys, motors, DAQ, PC, PLC, sample supports, linear sensors etc) from which two exemplar devices were constructed for the demonstration of system configurability to final year students upon their return from placement (Figure 3). The configurations meet the outline specifications derived from the students' project work with the pneumatic device operating at up to 10Hz, a theoretical maximum load of 1000N and maximum displacement of 40mm.

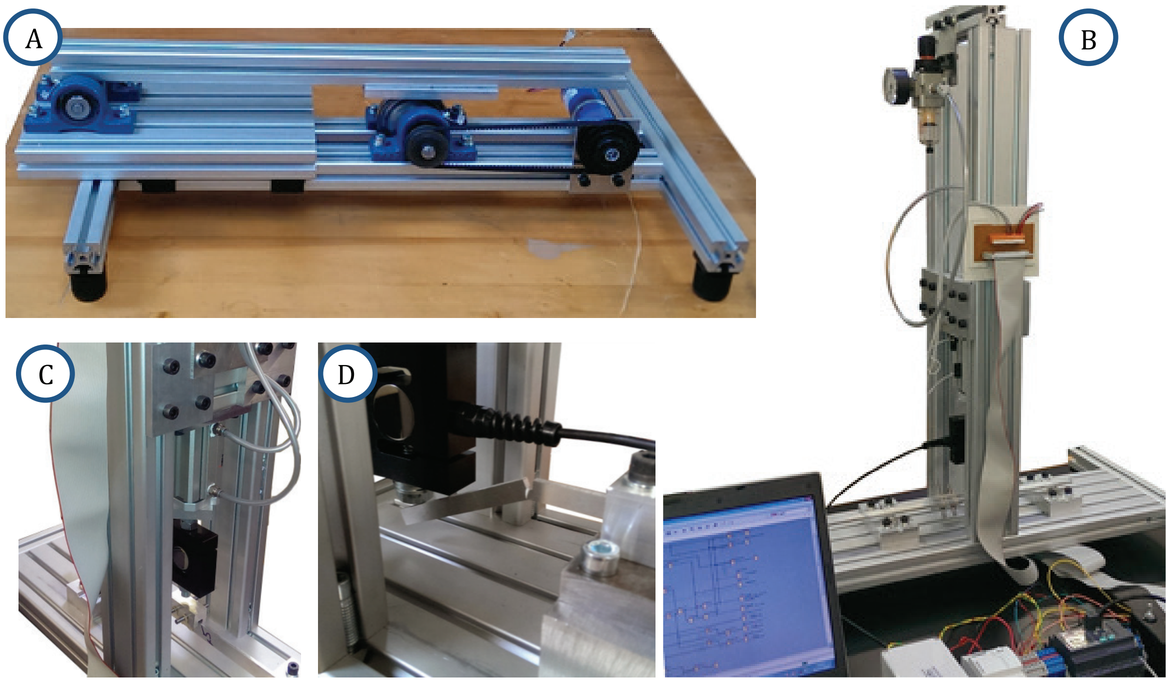

Figure 3. Exemplar configurations: A, Indirect loaded; B, Pneumatic system with PLC and load-cell; C, 4 point loading; D, Cantilever loading

5 CONCLUSIONS

The project, in conjunction with the development of the configurable elements and exemplars, satisfies the needs identified for both the 2nd year project unit and final year ATI. The project work itself allowed students to develop intrinsic interest in the subject area and knowledge of research methodologies (specifically in the area of fatigue and fracture mechanics) while satisfying their desire to design innovative engineering solutions.

The equipment, functionality and control systems described are derived from the students own designs, presenting familiarity of operation and capability. Students can now access hardware to build upon the foundations laid in the project, establishing a clear link between the two levels of academic study. These are adaptable in nature with a range of control options and framework elements presenting broader opportunities than the original cantilever scenario. They can be readily configured to directly represent the students own designs, presenting familiarity through the inbuilt adaptability of mechanism, control and data acquisition systems; this allows for rapid understanding of their operational characteristics hence short learning curve with equipment prioritised for undergraduate research.

Co-creation can be identified in two ways, directly through the co-creation of the physical hardware and through the co-creation of research outputs generated through the equipment developed.

The students draw upon and deepen their theoretical knowledge through practical application in the final year to the benefit of their academic development and future careers as design engineers.

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