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THE USE OF TEAM-BASED LEARNING AND REFLECTIVE FRAMEWORKS TO TEACH ENGINEERING DESIGN METHODOLOGY

Jeff BARRIE and Thea MORGAN
University of Bristol, United Kingdom

ABSTRACT
This paper provides research on innovative techniques and tools to teach different design approaches to engineering students, allowing them to compare and critique methodology, while enhancing knowledge and skills in each area. The paper investigates the value and scope of achieving this aim within a single teaching unit or module, where students undertake a series of short design projects, each using a distinct design approach to solve problems. The paper reviews the use of project-led approaches to teaching user-centred design, systematic design and social innovation to second year engineering students as a means to provide core design knowledge and skills required for different industries. The paper concludes with a discussion and conclusion as to how successful this approach has been-in terms of helping students understand the breadth of design methodology, compared to the more traditional, modular style observed on other design engineering courses.

Keywords: Team based learning, user-centred design, paper prototyping, rapid prototyping, service design

1 INTRODUCTION
The approach to engineering design practice may vary across different disciplines and institutions [1]. For mechanical engineering in particular, there is much focus on machine design and manufacturing, which is understandable given where Mechanical Engineers would fit within an organization or the process. A product design consultancy may have a dedicated team of Mechanical Engineers or Electrical Engineers who would specialize in prototyping, analysis and design for manufacturing. For example, Crux Product Design, based in Bristol, has divisions of expertise in design, mechanical engineering, applied science, electronics/software, human factors/usability and project management. DCA Design, based in Warwick, offer similar capabilities including industrial design and UI/UX design. For product designers and design engineers, an overview of the entire design process is vitally important for effective management, as well as the creative and ideation skills needed for conceptual development. However, there is some flexibility in where the skills and knowledge of a design engineer fit within an organisation, and in the last 10-15 years, a broader understanding of what can be defined as a 'product'. The role of an engineer is no longer restricted to 'tangible' products, but also software and service solutions [2].
There is a range of literature focussing on reviewing and improving systematic engineering design processes, from the early to late 1990's, which comment on disciplinary changes due to the implementation of CAD systems [3] [4]. What has emerged from the early 2000s, in parallel with the increase of web-based services and telecommunications, is that the Design Council's double diamond design process [5] establishes itself as a universal model for design and fits well within a new era of service and User-Experience (UX) design-which has become well adopted (and adapted) in the design field (See Figure 1.). For engineering, there has been an increased focus on systems engineering, integrating aspects of Mechanical, Electrical and Software Engineering. With many aspects of the double diamond design process and systems engineering referred to in scholarly research, but also books and guides derived from industrial practice, it indicates that design approaches have developed through pragmatic use as well as technological and societal change. Therefore, it's important for design engineers to be familiar with the range and variety of industry-relevant design processes across different sectors-as it is argued that design methods in practice go 'beyond' the systematic boundaries of Pahl & Beitz [6].

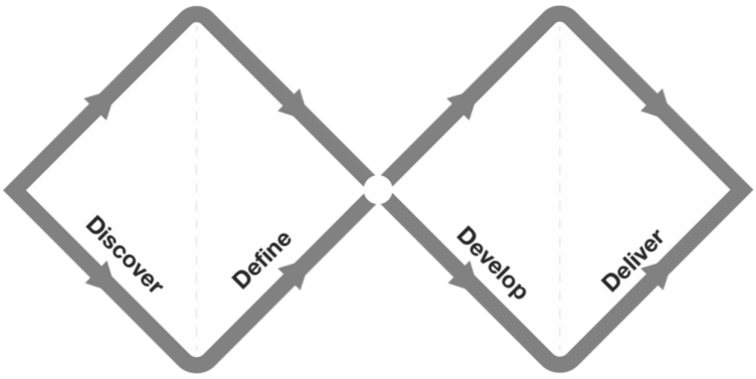

Figure 1. The Design Council's Double Design Process

2 TEACHING DESIGN METHODOLOGY-A DIFFERENT APPROACH

Other institutions that teach specialised design engineering programmes provide design modules that are tailored to their discipline, including aspects of Human-Centred design. For example, Design Engineering at Imperial College London offers modules that focus on Human-centred design, Sustainable Design and Industrial Design to students within the first 2 years of study. TEDI London's Global Design Engineering course also provides a module on Human-Centred Product Design in Year 2. As a skills and knowledge gap which was identified in the curriculum, a new design module was proposed and developed for second year engineering design students which took advantage of team-based learning to teach a range of different design processes and methods, due to the constraints of creating individual modules within the programme. The module was designed to make the most of video-based content and asynchronous delivery at the time, using a flipped teaching and thus offering the ability for students to take advantage of spending more contact time on project work (which proved advantageous when Covid-19 restrictions were imposed). The aim of this module was to expand students' knowledge and experience of design beyond their understanding of systematic engineering processes, adapted to help them understand key stages in the engineering design process. The simplified process is an adaptation of the Pahl and Bietz process (See Figure 2.)

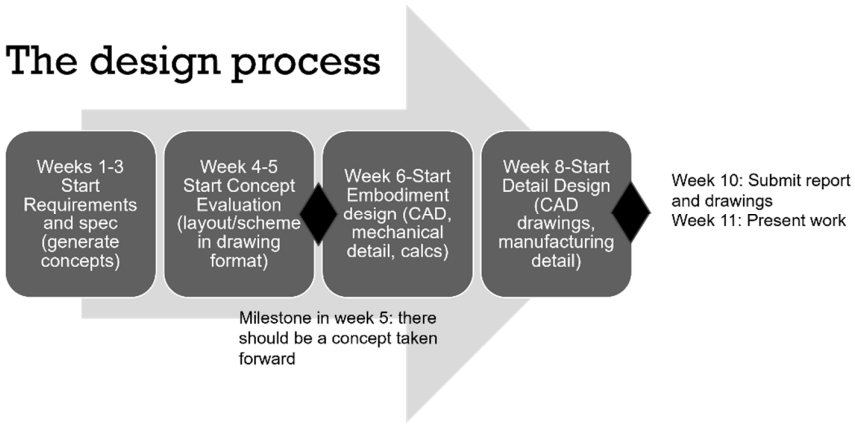

Figure 2. An adaptation of the Pahl & Bietz process into simplified stages

On the module, each design process is taught as a mini study, typically over four sessions which map to key stages of the process (for example, for the Double Diamond Design Process, this focussed on the Discover, Define, Develop and Deliver stages in each session). At the start of each session, a quiz was introduced to test and consolidate understanding at the start of each session. Students are also encouraged to record their reflections using learning diaries [7]. After each mini-study students present their design work to staff and peers. This is followed by an industrial workshop, which showcases the use of each process and methodology in a professional setting and offers some authenticity and

grounding to the teaching content. Students are assessed through a collective reflection of their understanding and experience within the unit, as well as an individual literature review to broaden their understanding of design thinking, prototyping and empathy tools. In total, three different design processes/methodologies are delivered within the unit, which are described in the following sections.

3 DOUBLE DIAMOND DESIGN PROCESS (THE OPENING GAMBIT)

The first mini-study introduced in the module was centred around the double diamond design process and included aspects of user-centred design and inclusive design methodology. Aspects of Stanford's D-School Design Thinking process was also introduced, and bears some commonality with the double diamond process, but makes a point of introducing empathy at the start (See Figure 3.).

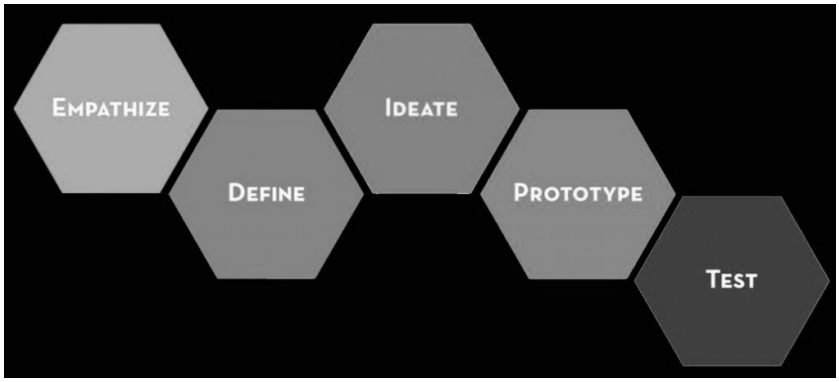

Figure 3. Stanford D-School Design Thinking Process

As a result, students made use of empathy tools from the outset. In this case, Cambridge simulation glasses and gloves, as well as software to help them understand physical and physiological challenges associated with older users, but to also understand how visual acuity and dexterity loss impacts the use of everyday products [8]. The mini study was framed around an assisted living design challenge, linked heavily with the Design Council's Living Well with Dementia [9] and Independence Matters [10] campaigns, to design a product and service for older users. They also make use of brainstorming, roleplay and character profiling as recommended by the Design Council and IDEO in a fast paced, creative studio environment. These methods, coupled with the lack of a clarified task (students had to research problems, bound them and define their own brief) assisted in putting students outside their comfort zone and facilitating group-based activities (which made this process a great introduction to the unit). Another D-School inspiration was the approach to low fidelity prototyping (in particular the use of simple materials such as felt, modelling clay and pipe-cleaners), which aligned with the Develop stage of the process. Students were also introduced to paper-prototyping techniques to develop aspects of the service design, such as the POP! Prototyping App that students could use with smartphones. (See Figure 4.) All techniques were able to be facilitated within a standard classroom setting without the need for specialist equipment. The mini study was concluded with a presentation followed by a workshop facilitated by Bristol-based product design consultancy, Crux Product Design, who use similar brainstorming techniques.

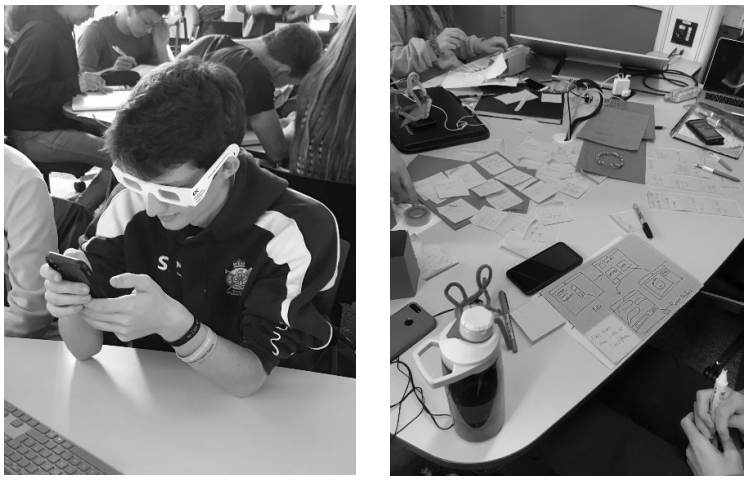

Figure 4. Left-Use of Simulation Tools Right-Use of Prototyping tools to develop Product and Service

4 PAHL & BEITZ DESIGN PROCESS (FAMILIAR TERRITORY)

The next mini study covered systematic engineering design processes, focussing mainly on the conceptual stages of Pahl & Beitz (See Figure 5.).

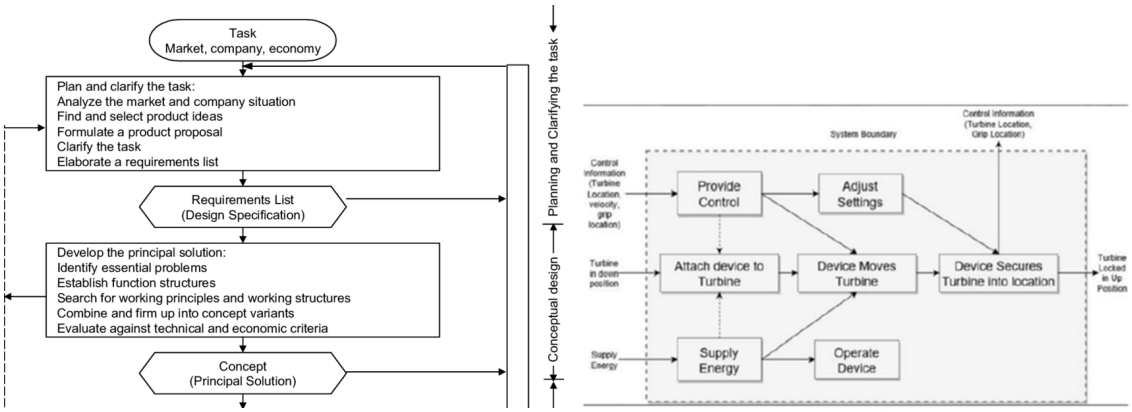

Figure 5. Right: The first section of Pahl & Beitz Design process and Left: Example of function structure for turbine raising system

With only four sessions, it was deemed unfeasible for students to cover the entire process and produce technical aspects, but rather a deeper and structured look into the initial design stages, in particular function structures. Students were familiar with elements of the engineering design process from first year, having covered morphological approaches and concept evaluation, however more rigour was applied for this level of study, through the creation of a requirements specification and use of function structures, which were new to students.

The design brief centred around the creation of a tidal turbine raising mechanism for maintenance and inspection-and involved breaking down the problem into sub-systems or sub-functions. An important element to understanding the process was using the output of the function structure as input into the working principles used the morphological approach. Students presented solutions at a conceptual level at the end of the mini study, followed by an industrial workshop facilitated by GE Aviation, which focussed on systems engineering.

5 SOCIAL INNOVATION DESIGN (SOMETHING COMPLETELY DIFFERENT)

The final mini study of the module really pushed the comfort levels of the students by challenging them to solve complex societal problems using a structured design process they would have not encountered

before. Using Kees Dorst's nine steps of frame innovation (See Figure 7.) students were be expected to tackle a social design problem that cannot be easily bounded, and to focus on developing an understanding of the values of stakeholders and re-framing. Such a process was inspired by early research in design thinking and design paradoxes [10] and then developed into a more practical and pragmatic methodology.

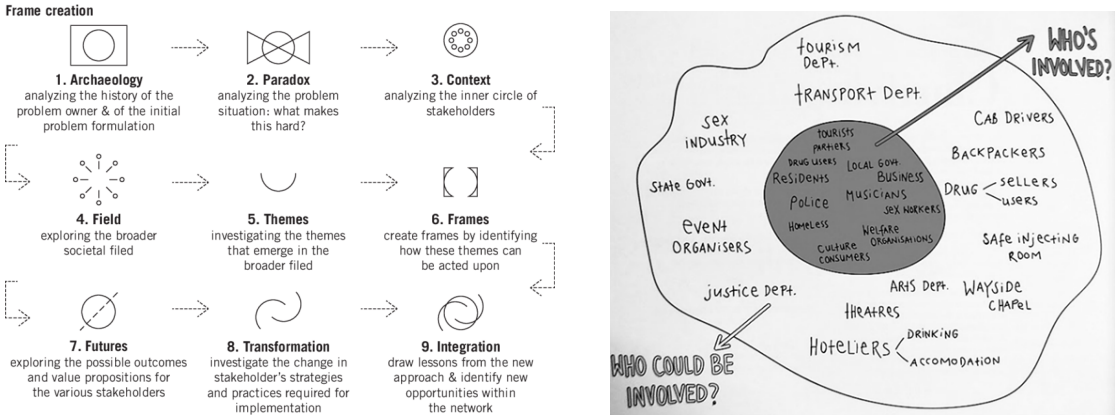

Figure 6. Right: Frame Creation process and Left: Example of stakeholder mapping (Kees Dorst)

Students focussed on the first 6 steps of the process and were able to explore some aspects of the Futures stage by engaging with a key stakeholder. Students were tasked with trying to solve problems associated with anti-social behaviour in a Hartcliffe, based in the city of Bristol. In previous mini-studies, students were able to either define or work with a bounded problem, and the frame creation process provides a different approach by considering all stakeholder and societal values, which is not typical for a design process. Despite the process for identifying key themes and frames being well structured, the conceptual design output may be of either low-fidelity or intangible. Students were provided with case studies to assist with their learning, in particular successful strategies such as the Scotland Violence Reduction Unit's (VRU) re-framing of knife crime [12]. Students were able to create visualisations of context and field stakeholder mapping as well as some interesting conceptual ideas. Students were able to discuss their ideas and gain better understanding of the issues surrounding the housing estate through their own city's VRU, led by the Avon and Somerset Police force.

6 DISCUSSION AND CONCLUSIONS

After a series of academic cycles, the following insights were gained from this approach, compared to teaching a single module on each topic:

- The mini studies had a degree of authenticity, in particular brainstorming, with a short turnaround time of a few weeks with a presentation/review at the end.
- All mini studies delved into the conceptual space of the design process, which was deemed a respite from the more technical aspects of the curriculum. Had students continued their conceptual designs into more detail, it would require the use of computers and software, which may disrupt the studio-based group dynamic. Students benefitted from undertaking short projects with a relatively low level of fidelity in terms of output (drawings, sketches and rough prototypes)
- Despite a short format, students were given more time on the conceptual side of each project than they would in other modules, which allowed them to explore the breadth of techniques available, such as using paper prototypes for service design. It was observed that some students found designing an 'un-tangible' product or service (e.g. an app) somewhat difficult.
- Another observation was that some groups went through the 'motions of a design process' rather than understanding stages (this was particularly evident in mini-study 2, using functions structures).
- There was a perception that initial research and clarification of task was sometimes rushed, for the sake of getting to concept development quicker, groups that spent more time delving into the context of the problem produced better and more appropriate designs.

- Introducing social innovation was conceptually challenging, given it was an un-bounded problem, but necessary for wicked problem solving in modern-day engineering. Social Innovation can be seen as interlinked-and an important aspect to learn about in design for sustainable development [13]

The benefits of introducing such design approaches and techniques as single modules are that learning outcomes and assessments are neatly mapped out, with significant time and detail for students to develop a design solution from start to finish. One can argue that such a modularised approach prevents students from understanding a disciplinary or programme narrative, especially at early levels of study. Second year is where core knowledge and skills are developed from the foundations of first year, but it's a step too far to say that students at this stage of study are well-versed in design methodology, but more-over given a broader experience of the variety of different design approaches and assessed through critique and reflection (rather than directly through design outcomes themselves). More advanced skillsets and knowledge may be better placed in the third year of study, with the possibly of specialisation in certain pathways. For comparison, Stanford D-School's integrated undergraduate programme structure is designed to provide an engineering base, design core, methods depth followed by domain-focus, culminating in a capstone design project. In the same vein, much can be learned from playing around with breadth vs depth, when it comes to design methodology.

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