DEVELOPING CREATIVE ENGINEERS: A DESIGN APPROACH TO ENGINEERING EDUCATION

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ABSTRACT
Despite an increase in calls for reform of engineering education, engineering faculties continue to focus somewhat narrowly on the science of engineering, without sufficient curriculum opportunities for students to develop either design skills, or creative methodology. Design is fundamental to engineering practice, and therefore should be a motivating factor in engineering learning. Without focussing on design activities and creativity, we will continue to graduate engineers who are competent technically, but not prepared for the practice of engineering nor the challenges of the 21st century. A cultural change is warranted in engineering, as is reform of the established theory-based curricula; currently there is little emphasis on experiential learning through design or the development of creativity. By contrast, design pedagogy fosters creativity by developing and nurturing problem solving skills and providing regular opportunities for students to refine these skills through experiential project-based learning. Creative activities such as ‘reflection in action’, problem framing, divergent thinking and open-ended problem solving are integral to the designer’s education, but are notably absent from engineering curricula. Yet creativity is central to innovative problem solving and as such should be integral to the education of engineering designers. To be creative, engineers must desire uniqueness, accept unusual ideas, tolerate the unconventional and seek unexpected implications. In this regard, the engineering community can benefit from close observation of design pedagogy.

The Product Design Engineering paradigm with its integration of engineering and design curricula seeks to develop creative engineers through the utilisation of design educational processes in an engineering learning context.

Keywords: creativity, engineering design, engineering curricula

1 INTRODUCTION

It is implicit that creativity is integral to design innovation, and that design and the fostering of creativity should be the cornerstone of engineering pedagogy. “The purpose of engineering education is to graduate engineers who can design.” [1] Yet whilst many academics and professionals express dissatisfaction with traditional engineering pedagogy (Dym, Akay, Beder, Pappas, Wulf and others), many engineering faculties continue to focus narrowly on the science of engineering, denying students the opportunity to develop design aptitude or an adaptive and creative approach. “Engineering is, by nature, a creative endeavour, but many engineering colleges fail to address this, and end up training engineers for technological task completion.” [2] Beder [3] has called for cultural change through which students will “develop innovation and creativity”, sentiments echoed by Akay [4] who advocates the need for a ‘renaissance’ engineer who is a creative thinker.

Unfortunately, these challenges have been fundamentally unanswered, prompting a response from engineering regulatory bodies worldwide. In the United Kingdom, the SARTOR (Standards and Routes to Registration) accreditation document by the Engineering Council requires universities to show how graduates could achieve “the ability to be creative and innovative”. This position is comparable with the US Accreditation Board for Engineering and Technology (ABET) which has emphasised its desire to foster creativity in design.

Yet despite awareness of the limitations of ‘traditional’ technical theory-based curricula, it is apparent that we do not teach the language of design, preferring instead the language of mathematics. [5] Engineering curricula typically do not invest in design activities, or the learning of creative tools often until the final year(s) if at all. It is common for graduates to lack proficiency in resolving ill-defined

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problems, and experience in real world project-based learning. However without a focus on design activities and creativity, we will continue to graduate engineers who are competent technically, but not capable of innovation. “University has to foster creativity” [6]

The Product Design Engineering program at Swinburne University of Technology offers an integrated program of design and applied engineering, producing graduates who balance a scientific and analytical approach with the ability to take calculated risks to solve ‘wicked’ design problems. Students are instilled with the ‘tools of design’, such as sketching and model-making in the foundation years, and creative design skills are developed throughout the course. The curriculum responds to Dym with an attitudinal shift that is “toward a more explicit recognition of design as a distinguishing feature of engineering practice and a motivating factor in the learning of engineering.” [5]

2 THE CREATIVE ENGINEER

“As educators, we are responsible for stimulating creative thinking among our students... Our ultimate goal is to require original creative work as part of every engineering course” [7]

2.1 The need for creative engineers

Some still question the importance of a focus on creativity in engineering education. Are not engineers normally engaged in pragmatic problem solving, where simple, cost effective ‘known’ solutions are preferable over creative solutions that require extensive investigation and resolution? The design and engineering disciplines are purportedly dissimilar, “engineering is a scientific and analytic profession; design is constructive, a pattern of behaviour employed in inventing things of value which do not yet exist”. [8] Nevertheless we are educating in a rapidly changing environment and must anticipate industry expectations and the emerging responsibilities of the new design engineer.

“Creativity is of paramount importance in engineering for it endows one with insight and discipline to seek out and address problems from the boundaries of different engineering disciplines” [9]

In a uncertain economic environment with diminishing resources, the onset of climate change and the need for sustainable design, a new engineer is required; one with a design philosophy that seeks unexpected and innovative solutions through applied creativity. However a fundamental change is required to achieve this; engineers must be taught not to be distrustful of creativity, but instead to welcome the unexpected and be confident working outside their comfort zones of science and method.

2.1 Defining creativity in an engineering context

Creativity involves having unusual ideas, tolerating the unconventional and seeing unexpected implications. [10] This can be particularly challenging for engineering students who are more comfortable working within defined parameters and values and who tend to fixate on prior solutions. Fry [11] notes that traditional engineering assignments tend to be left brained and highly defined with specific steps and predefined correct answers. These styles of curricula do not encourage the development of creativity thinking which requires “a non-linear, unstructured and flexible approach to solving problems and generating ideas.” [2]

However to define creativity to engineers as an ‘approach’ which involves flexibility, fluency, novelty and definition, [11] rather than resulting from ‘ex nihilo’ (out of nothing) can assist student acceptance and willingness. “Making the strange familiar – accepting creativity as a desirable mindset and attribute of engineers – is a tangible and realisable goal.” [12] It is essential that student engineers are comfortable and confident with the creative process; this can only be achieved through extensive experiential learning with creative methods in the engineering design process.

Creativity, in the context of engineering design, should be seen as leading to innovative problem solving and must be developed and nurtured at all stages of the learning process. Students must be challenged to move beyond the technical aspects of the problem.[12]

2.2 Engineering languages – the place of creative design in the curriculum

Creativity is the essence of engineering. Yet creativity is neither explicitly taught nor promoted in the engineering curriculum. [13] The regulatory body responsible for engineering course accreditation in Australia, the Institution of Engineers Australia, has stated that a new engineering focus is required. Its National Panel on Design position paper states that as “design is a primary function of the engineering profession,” engineering education should encourage an applications-oriented framework to teaching engineering science material and a greater emphasis on project work of a design nature.” [14] “One of
the consequences of design-focused education is that students learn that they are applying knowledge in differing forms to serve different ends, which means that they can become fluent translators of engineering languages." [5] Although this is understood in academic circles, it is not always evident in engineering curricula, due in part to the fixation with the teaching of engineering science. This is despite calls for greater creativity which date back to the shocked reaction to the 1957 Sputnik launch. Both Fox [15] and Cross [16] have identified that there is an ‘educational justification for design’ as a means to develop cognitive skills and real-world problem solving abilities. To achieve this, design needs to move from the periphery to a central role in engineering education.

2.3 Wicked problems
It is apparent that many of the problems facing the 21st century design engineer will be ill-defined problems; design problems that are not amenable to the techniques of science and engineering. These ‘wicked’ problems [17] will require a co-evolution of problem framing and solving, divergent and flexible dichotomies, creativity and a lack of fixation on prior solutions. Hence a new engineering approach is required. The new engineer should add not only functionality, but also value, and introduce change. This can be achieved through open ended design problems which “force students to think creatively and ultimately foster in them an appreciation for developing creative solutions”. [9] To address ill-defined problems, engineers must be confident seeking solutions outside their traditional fields of expertise, using intuition rather than mathematics, and pursuing innovation.

3 CURRICULUM
3.1 Developing creativity
Early approaches to fostering creativity concentrated on the training of specific skills (e.g. Osborn’s brainstorming). However Cropley argues that this ignores the non-cognitive aspects of creativity such as motivation and self-confidence and Feldhusen concluded that student creativity can be enhanced, by teaching them to seek new ideas, recognise novel approaches and judge the effectiveness of novel solutions. Engineering programs need to create positive attitudes towards creativity, motivate students to be creative and innovative, encourage student confidence in their creative potential and reduce anxiety about unexpected solutions in problem solving processes. [18] It is insufficient to engage engineering students in problem-based learning exercises which prove only their knowledge of the ‘science’. To develop knowledge into aptitude, students require experience. Experience in the ‘practice of engineering’ should be obtained through rigorous challenges requiring creative design solutions, and though experiential learning processes that apply engineering theory to scenarios requiring design resolution. Creative exercises and design projects generate excitement in students when engineering problems are addressed in original or unexpected ways, and science is applied to real world outcomes.

3.2 Sketching and innovation
Compounding the lack of focus on design in engineering education is the disregard for teaching basic design conceptualisation and articulation tools such as sketching. “Sketches help the designer to not only make ‘vertical transformations’ in the sequential development of a design concept, but also ‘lateral transformations’ within the solution space: the creative shift to new alternatives.” [19] Without sketching ability, engineering students struggle to uncover the unintended consequences, the surprises that keep the design exploration going in what Schon and Wiggins [20] described as the ‘reflective conversation with the situation.’

“It is in considering how these sketches help an idea take form, that gives a hint that drawing’s role in engineering is more than just to archive a concept or to communicate with others.” [21] Whilst 2D/3D CAD software is taught as part of engineering documentation studies, there is little evidence that sketching, the tool with which engineering designers articulate their thoughts (for problem framing, discussion and reflection) is valued in engineering education curricula. This is despite significant research that links sketching to creativity. Engineering students must be taught to sketch and be less reliant on CAD which stifles creativity by imposing its methodology on the user.

3.3 Learning from design pedagogy
“Industrial design students are asked to focus on novelty and originality, looking for new contexts and opportunities for innovation within a broad general framework. Engineering students predominately
work to define a set of parameters and target values up front that would define a specific, successful solution within a narrow range. These two mindsets often clash as one seeks to broaden the scope of the problem, while the other is working to achieve closure.” [11]

Designers use tacit, episodic, socio-cultural and experiential knowledge. They are comfortable with risk taking and ill-defined problems, and utilise objective, subjective and emotional decision making processes. Product designers face uncertainty in the areas of context and emergent properties. This is in contrast to engineering designers who are typically occupied by technical issues or clarification uncertainties and rely on adaptive design processes. It is common in the early stages of the design process for the designer to know nothing of the goal, a situation where “notions of process, environment and implementation are neither precise nor verifiable”. [22]

As we acknowledge that “convergence is at the core of the engineering process, and divergence at the core of the industrial design process” [11] it becomes apparent that the path to creativity in engineering must incorporate significant learning from design pedagogy. Engineering curricula must incorporate opportunities for students not only to apply their ‘science’ in a real world context but to freely explore possibilities unconstrained by limitations and parameters. However “students must be aware that instruction in creative thinking will not provide the certainty offered them in most engineering tasks. Creative thinking is a more ambiguous endeavour than most engineers are used to or skilled in...there are no right answers” [2]. This is dangerous territory for the engineer who seeks to define solution through applications of mathematics and science.

### 3.4 Open ended problems

Experience of open-ended problems develops divergent and flexible dichotomies, problem framing abilities, a reflective approach and the skills to successfully resolve poorly defined problems. [23] These are the tools that lead to creativity and subsequently, product innovation.

Recent ongoing comparative evaluations have been conducted by the author between product design engineering (PDE) and mechanical engineering students at Swinburne University of Technology. These comparative projects have revealed that the PDE students (who are familiar with ‘designerly ways’) are confident and proficient with open-ended problems. However the other engineering students struggled to define and then resolve problems, without material or functional constraints to guide the project direction.

To produce creative design outcomes, engineering students must learn to define the problem in both divergent and convergent modes and be flexible, fluent and original in approach.

Interestingly, the comparison also included a heavily constrained and very technical project in which the PDE students also excelled, due to a more creative and flexible approach to the design process.

### 3.5 Project based learning

“Teaching creativity has limited impact if it is not immersed in problem solving exercises.” [13] One of the greatest criticisms of traditional engineering pedagogy is that it is a theory based science model that does not prepare students for the ‘practice of engineering’. By contrast design pedagogy fosters creativity and develops problem solving ability skills through a ‘learning in action’ experiential process. Project based learning is integral to the design learning program which instils the tools of design practice and communication (including sketching) early in the curricula and then allows significant opportunity for development of skills and confidence building. Engineering students require the opportunity to apply their science to resolve design solutions, through project-based learning, rather than problem solving activities that do not provide a tangible outcome for evaluation. Creative engineers are described as those who are driven to seek uniqueness and unexpected implications, develop unusual ideas and tolerate the unconventional. [10] These are characteristics also used to define designers and are common themes in design education, but rarely in engineering.

Engineering curricula must be reformed to afford students experience in real world design through a project-based learning process that allows creativity to emerge.

### 3.6 Integration and multidisciplinary learning

In Engineering Design Methods; Strategies for Product Design, Nigel Cross notes that “the increasing competition for consumer markets and the growing awareness of the importance of design for the market has led to reinforcement of the view that successful design can only be accomplished by an integration of the skills of both engineering and industrial designers.” [16]
This is particularly true in the product design and development (PDD) environment where multi-disciplinary teams engage to realise complicated product solutions. There is emerging evidence that integrated learning is an ideal pedagogy due to cross-curricula connections and student exposure to diverse and contradictory positions and environments. In this regard, one way to introduce reform to engineering curricula is through new pedagogical models that eradicate traditional rivalries and mistrust through new synergies and collaboration.

### 3.7 Product Design Engineering - an alternate pedagogy

The Product Design Engineering program at Swinburne University of Technology represents a different approach to engineering education. Through an integration of industrial design and mechanical engineering it aims to develop a creative and adaptive engineering designer, one who can anticipate and address the changing needs of societies and environments with responsible and innovative solutions. It has been particularly successful with the integration of ‘designerly ways’ into the engineering curricula without compromising the integrity of the science of engineering. Contrary to expectations, the Product Design Engineering students have proven to be even more adept at their engineering due to their ability to apply science to real world problems. Whilst they excel at ‘wicked’ problems, it has been found that they are significantly better at problem framing and technical resolution than other student engineers, even when faced with highly technical problems. This is a result of their extensive design project experience, high level sketching and modelling ability, reflective approach and well developed creativity. In the product design engineering program, design subjects utilize the in-class services of an experienced engineering practitioner for technical support and to ensure industry relevance. Project outcomes are required to apply engineering science in the context of a design problem. The product development ‘approach’ is unique and differs from that of the industrial design students in that products are designed from the ‘inside out’ – the product architecture is specified and engineered before the product is designed. This ensures that the processes of engineering methodology are fully integrated into the design process.

It is required that all student outcomes exhibit creative design and innovative engineering solutions. Students are expected to seek ‘novel’ outcomes whilst utilizing new or emerging materials and technologies. Originality, creativity and passion for design are the hallmarks of these new engineers. Product design engineering occupies a unique position, juxtaposed between the ‘adaptive’ design space of the engineer and the ‘new’ design space of the industrial designer. Consequently, this multi-disciplinary course is not without its cultural and pedagogical issues. The nature of design and engineering processes are disparate, as are the specific aptitudes required for successful professional practice. Nevertheless product design engineering students and graduates have successfully bridged the discipline divide by integrating ‘designerly ways’ into a thorough and technically grounded engineering approach.

### CONCLUSION

We need “a new generation of adaptable, flexible, well rounded and innovative professionals” [12] Above all, engineering must look to design pedagogy as a model for the fostering of creativity and innovation through a structured program of design integrated throughout the curriculum, with project-based learning utilised extensively to teach the practice of engineering, not just the science. The product design engineering model is one example of how these needs can be addressed, without compromising the integrity of the science of engineering. Similar programs exist in many different variants, but with a singular focus; to develop human-centred and creative engineers. What is more important than the success of one specific pedagogy, is the potential for this teaching approach to contribute to improved learning and graduate proficiency across engineering disciplines. Other engineering curricula could significantly benefit from a systematic evaluation of this new engineering paradigm. We must imbue the new generation of engineers with the appropriate skills to deal with a rapidly changing world that is in desperate need of creative and innovative engineering. The challenges of educating the generation in whom we entrust the future cannot be achieved with outmoded engineering curricula. The future requires engineers who are thoroughly prepared for the challenges that face global communities; water shortages, global warming, environmental degradation, energy and material consumption, sanitation, carbon emissions and demographic and cultural shifts. In a rapidly changing world, creative solutions are required.
This is not the time for pragmatic problem solving and ‘known’ solutions, a new engineer is required; one with a design philosophy that seeks unexpected and innovative solutions through applied creativity. These new engineers must be comfortable with the unexpected, be flexible and adaptable, and most importantly seek to provide innovative design solutions through a balance of divergent and convergent thinking coupled with creative engineering practice.

Current engineering curricula will not achieve this, pedagogical reform is required.

REFERENCES


