INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED13
19-22 AUGUST 2013, SUNGKYUNKWAN UNIVERSITY, SEOUL, KOREA

REFLECTIONS ON THE CHALLENGE OF DEVELOPING PROFESSIONAL ENGINEERING DESIGNERS AND ENGINEERING DESIGN TECHNOLOGISTS – A NEW ZEALAND PERSPECTIVE

Antony John ROBOTHAM, John Kenneth RAINE, Roy Jonathan NATES, David Edward WHITE
Auckland University of Technology, New Zealand

ABSTRACT

This discussion paper reflects upon the 100+ years of experience of the authors in delivering tertiary level education to engineering designers. It compares the teaching approach taken for professional engineers and engineering technologists and promotes the need for T-shaped designers. The merits of a project-led approach to engineering design is discussed and an outline for an inter-disciplinary Masters level programme is considered. The discussion combines the reflections of the authors with some of the latest research into design education.

Keywords: design education, design practice, design engineering, t-shaped designers, inter-disciplinary design

Contact:
Dr. Antony John Robotham
Auckland University of Technology
School of Engineering
Auckland
1010
New Zealand
tony.robotham@aut.ac.nz

1 INTRODUCTION

This discussion paper reflects upon the combined experience of the authors in developing tertiary level educational programmes for engineering designers. Our experience not only derives from delivering engineering design as a core curriculum element of the engineering programme but also as the integral essence of design-led, project-based engineering programmes, collaborative programmes that combine elements of engineering design with product/industrial design, our personal involvement with engineering industries, and design research.

As an academic team, we have only recently come together and begun collaborating on the development of the next generation mechanical engineering design curriculum at the Auckland University of Technology in New Zealand. However, despite a collective experience of over 100 years in the university sector, we continue to be challenged by the educational development of engineering designers in respect of learning objectives, curriculum content, teaching approach, academic rigour, and professional competencies at each and every level of our taught programmes.

Over the last 20 years or so, the engineering design knowledge domain has expanded significantly and features both technical and non-technical elements. Our desire is to use the “Design Science” (Hubka and Eder 1996) that has emerged, e.g. through the WDK/Design Society conferences and publications, to underpin our curriculum and teaching approach. However, to contribute to this research domain often requires a different style of research approach and create outputs that do not sit comfortably within the classical research quality measures for “Engineering Science”. As academics specialising in engineering design working in schools of engineering we will be “measured” against engineering scientists whose research is laboratory based and numerically biased. Excitingly, the School of Engineering at AUT sits within a Faculty of Design and Creative Technologies, which provides us with new opportunities to work on collaborative activities in teaching and research with designers from other disciplines – we believe this gives us a real advantage for the creating exciting challenges for teaching and research.

This paper draws from our observations of past practice, current and future requirements, and outlines an approach to the education of engineering designers that is durable, adaptive and economic to deliver. We also briefly describe our intentions for a Masters level programme that help fully form our graduates into the innovative, creative engineering designers demanded by future challenges.

2 BACKGROUND

The Auckland University of Technology is New Zealand’s newest university although its origins date back to the opening of the Auckland Technical School in 1895. With its original focus very much on vocational education, the institution evolved into a polytechnic (Auckland Technical Institute) in the 1960s and introduced the country’s first full time technicians’ course, the New Zealand Certificate in Engineering. In 1989 the renamed Auckland Institute of Technology gained autonomy and the right to confer degrees and then became the first New Zealand polytechnic to become a university in 2000 – Auckland University of Technology (Shaw, 2002).

The School of Engineering currently offers 4-year undergraduate Bachelor of Engineering (Honours) degrees in Mechanical Engineering, Electrical & Electronic Engineering, and Biotronics. Also, reflecting the School’s vocational roots, there are 3-year Bachelor of Engineering Technology degrees in Computer and Mobile Systems, Electrical Engineering, Electronic Engineering, Mechanical Engineering, and Network & Communications Engineering. The Bachelor of Engineering (Honours) and Bachelor of Engineering Technology are accredited respectively under the Washington and Sydney Accords through the Institution of Professional Engineers of New Zealand (IPENZ). New maritime majors in Naval Architecture, Ocean Engineering, and Marine & Offshore Engineering are being launched in 2013 in partnership with the Australian Maritime College in Tasmania. The School of Engineering is part of the Faculty of Design and Creative Technologies alongside the Schools of Computing & Mathematical Sciences, Art & Design, and Communication Studies. The portfolio of undergraduate bachelor programmes and the majors available in the Faculty is shown in Figure 1. The inter-disciplinary Bachelor of Creative Technologies is an independent degree combining knowledge from all the schools in the Faculty.

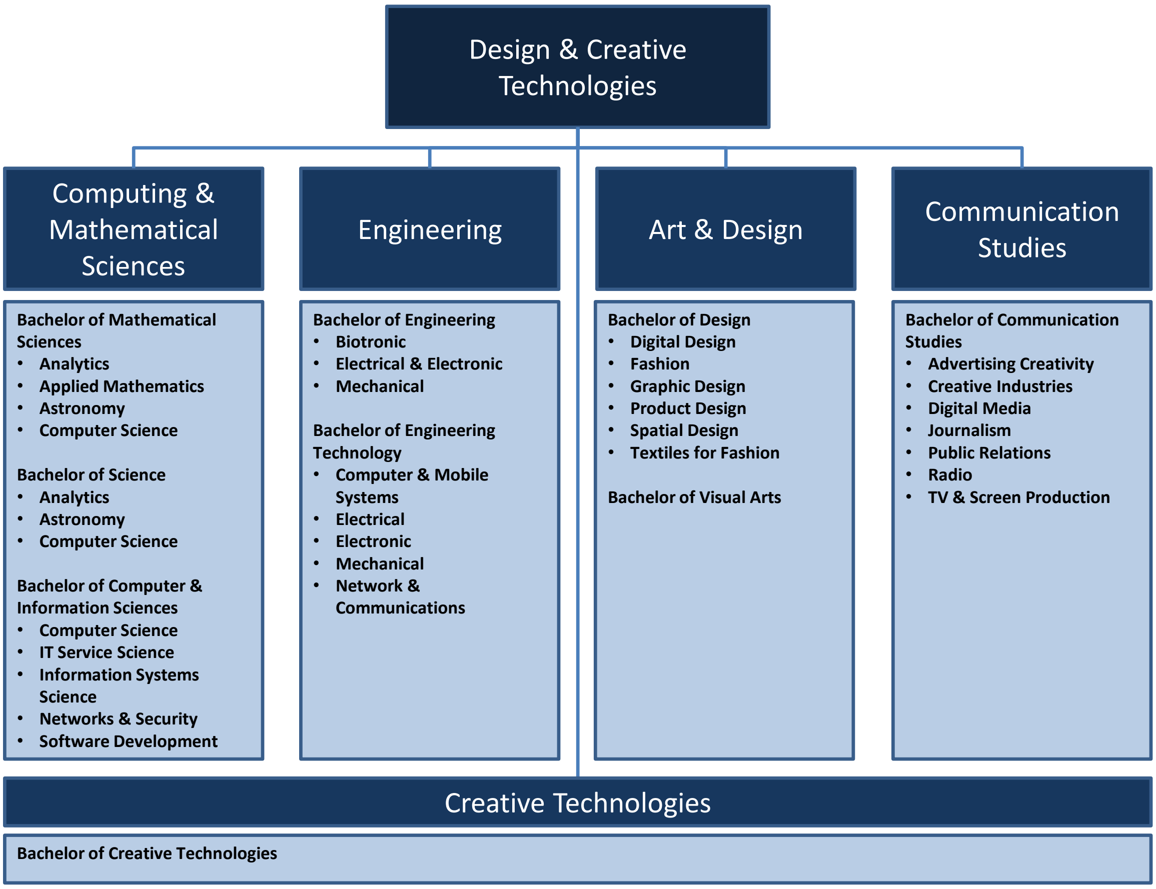

Figure 1: Undergraduate Degree Programmes and Majors in the Faculty of Design and Creative Technologies at Auckland University of Technology

3 THE FORMATION OF PROFESSIONAL MECHANICAL ENGINEERS AND TECHNOLOGISTS

The Mechanical Engineering undergraduate degree programmes have been devised to provide vocational and professional careers in engineering. Consequently, the 4-year Bachelor of Engineering (Honours) programme has been accredited by IPENZ in accordance with the Washington Accord and fulfils the initial academic requirements for qualification as a *professional engineer*. Similarly, the 3-year Bachelor of Engineering Technology programme has been accredited in accordance with the Sydney Accord and fulfils the initial academic requirements for an *engineering technologist*. “Engineering synthesis and design” is core to both programmes as they are considered to be “a defining characteristic of professional engineering endeavor” (IPENZ, 2010). Common ideas and requirements for both pathways in respect of engineering synthesis and design are:

- Engineering design is the process of devising a system, component, or process to meet specified needs.
- The decision-making process is iterative and applies the basic sciences, mathematics and engineering sciences to optimally convert resources to meet stated objectives.
- Students should develop an understanding of classical design methodology, which includes the formulation of design problem statements (objectives) and specifications, consideration of alternative solutions, synthesis and evaluation, prototyping/simulation/modelling, construction, testing and evaluation.
- Design should be integrated throughout the programme and should include team efforts.
- Students should undertake engineering design and related project work, particularly through a meaningful design experience in the final year that builds on the programme’s technical foundations and provides an integrated opportunity to demonstrate a range of targeted graduate outcomes.

However, the expectation is that professional engineers will:

- Develop creativity; develop solutions to open-ended problems; develop and use modern design theory and methodology; formulate design problem statements and specifications; consider alternative solutions, feasibility considerations and production processes; and develop detailed system descriptions.
- Apply research and analytical skills to design activities.
- Consider various realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics and social impact

Whereas, the expectation is that engineering technologists will:

- Apply a range of analytical and problem solving tools and techniques to analyse broadly defined engineering problems.
- Apply classical design methodology to develop solutions to broadly defined engineering problems.
- Consider realistic constraints and compliance factors

Fundamentally, when we look at these requirements, the expectation is that both types of engineer should acquire a thorough grounding in design methodology and that this should be learnt through practice, i.e. designing. However, the difference between professional engineers and engineering technologists occurs in the complexity of the problem to be resolved (i.e. open-ended vs. broadly defined problems), the depth and breadth of Engineering Science being applied (i.e. using first principles vs. analytical tools, general engineering vs. practice area knowledge), and the breadth of contextual issues being dealt with (i.e. open-ended vs. broadly defined problems).

These differences in depth and breadth of capability can be can be represented by characterising designers as T-shaped people, where the horizontal bar represents the breadth of their design capability and the vertical bar represents the depth of their engineering knowledge. Using this analogy, we would argue that professional engineers would evolve through professional practice to be large-T (T-shaped) designers, whilst engineering technologists, by comparison, would more likely to be little-T (t-shaped) designers (Figure 2); but more about that later.

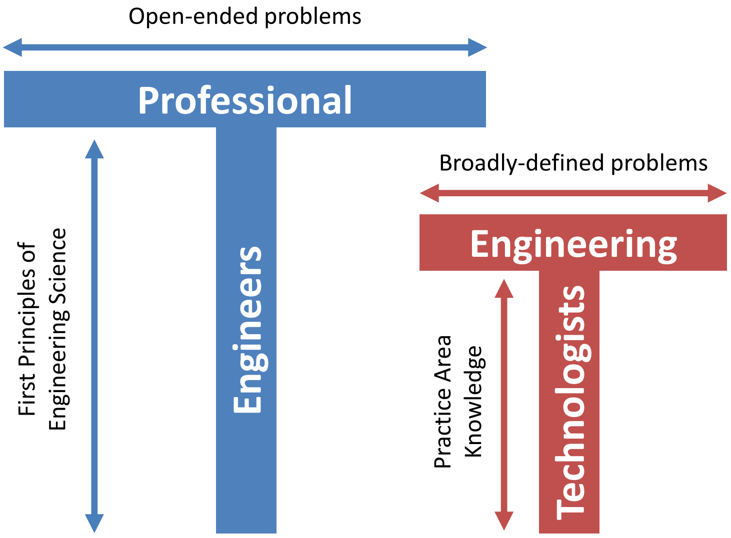

Figure 2: T-shaped professional engineers and t-shaped engineering technologists

4 SO HOW SHOULD WE TEACH MECHANICAL ENGINEERING DESIGNERS?

During the review of our Mechanical Engineering programmes for re-accreditation in 2013, there was an opportunity to revise all the engineering design papers. Our challenge was to devise an engineering design curriculum that can fulfil the requirements for each vocational pathway, but which is durable and adaptive to future needs and “economic” to deliver. Much of our debate concentrated on whether it is feasible to have a single set of papers at each level that satisfies both programmes of study, or whether the formation of professional engineers needs to be fundamentally different to that of engineering technologists?

Our current thinking is the result of our combined experience; the fundamental principles of the approach we are looking to deploy are:

1. Programme specific learning outcomes – the learning outcomes for graduates of the Bachelor of Engineering programme need to be differentiated to those of the Bachelor of Engineering Technology programme.
2. Level specific learning outcomes – the differentiation between the two programmes also needs to be reflected at each level of the programme.
3. Product and Process knowledge – the curriculum should enable students to create a technical solution to a problem using a well-defined and understood methodology.
4. Learning through doing – the knowledge and skills of engineering design need to be acquired through designing in a project-led approach.
5. Competency of the individual – essential and obvious, but individuals should not be able to hide behind the team; graduates must have a well-defined design competency.

Whilst our approach may not appear to be novel in anyway, we believe it is important to re-iterate why such a robust learning and teaching method is being maintained when more innovative approaches might be expected. Our justification follows.

4.1 Programme specific learning outcomes

The programmes fulfil the initial academic requirement for qualification as either a professional mechanical engineer or mechanical engineering technologist. We must respect that these are equally valid pathways to a career in engineering so each must have its own set of learning outcomes.

Entry qualification requirements are more demanding for the bachelor of engineering programme than for the bachelor of engineering technology and, with 4 years study, the learning outcomes will be set at a higher level. Furthermore, with 4-7 years of industrial experience, graduates will be able to register as a Charted Professional Engineer (CPEng) or Engineering Technology Practitioner (ETPract), which are quite distinct occupational groups in the engineering profession (IPENZ, 2010).

Whilst we like the analogy that professional engineers need to become T-shaped and that engineering technologist will be t-shaped, we also want our students to have clarity about their identity and ensure that they are firmly grounded in their technical discipline. Above all we want them to acquire “designerly” ways of knowing, thinking and acting (Cross 2000).

4.2 Level specific learning outcomes

The learning outcomes of the Bachelor of Engineering programme are not achieved merely by an additional year of study over the Bachelor of Engineering Technology. We need to see differentiation between the two programmes at each and every level. The students on the Bachelor of Engineering programme need to acquire professional engineering prowess through 4 years of continuous learning and application through engineering design at a greater depth and breadth than those on the Bachelor of Engineering Technology programme, Figure 3. At each and every point of the programme we should impose different demands and assess different outcomes between the two.

This principle is also reflected in the pathways to professional qualification, which demands that a graduate of the Bachelor of Engineering Technology should undertake a minimum of 2 years extra study to migrate to the same pathway as a graduate of the Bachelor of Engineering (IPENZ, 2010).

The inference from this principle, is that the students need to be taught independently of each other; this is not necessarily true for engineering design, where the challenge to learning is not necessarily about richness of curriculum content but more about complexity of problem to be solved and the depth of knowledge and breadth of methods used to achieve a solution. This will be expanded upon below.

4.3 Product and Process knowledge

Design is both a noun and a verb (Lyon, 2011); the noun referring to the objects, products and services created through the process of designing (the verb). In his recent study of how design engineers spend their time, Robinson (2012) found that design engineers generally spend 54-68% of their time on technical work associated with the product. Similarly, over 57% of their time was spent engaged in the design process, which involves technical and non-technical; two-thirds of this time was associated with capturing requirements, creating solutions, and capturing solutions. Our ambition would be that we achieve similar levels of commitment to the creative process from our students. But more importantly, it is essential that engineering design teaching develops competency in the student to systematically follow a process that results in a robust technical solution. It therefore follows that assessment should distinguish between product knowledge and process knowledge, and that the student's competency in both dimensions must be evaluated.

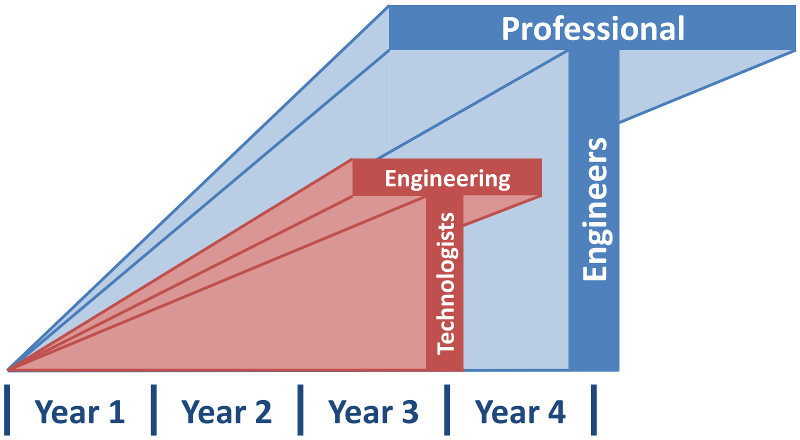

Figure 3: Professional engineers need greater depth and bread at every level

We do not have the opportunity here to describe the proposed curriculum in detail, but our ambition is to introduce aspects of Design Science that have been sadly lacking in previous programmes – for example, a rigorous theory of technical systems that enable students to describe the architecture and functionality of their solutions at all levels in the system. Similarly we need to embed a thorough understanding of the design process so that students can identify the tasks to be undertaken in their work and execute a coherent plan of action in a timely manner. The scope of the work undertaken will broaden through the programmes as the complexity of the projects undertaken evolves and focus is given to different design phases, i.e. planning, concept, embodiment, and detail.

4.4 Learning through doing

Lyon (2011), in her review of UK design education, notes that practice-based design is an integral part of design education, which allows learners to pursue their own strong interests, provides a trigger for creativity and imagination, and allows experimentation with their knowledge. She reports that design can change how students learn with a shift from teacher-led to learner -orientated learning and teaching; students become more active learners and learn about themselves through the things they make, and the design-practitioner teacher becomes a mediator between academic knowledge and the learner. She notes that integral to this style of teaching is the design studio – a place and a process.

We have no doubts that engineering design should be learned through the creative process of designing and whilst there is a good deal of Design Science that could be relayed through other classroom methods, the mastery of engineering design comes through doing. Consequently, engineering design students will learn through undertaking design projects.

However, we regard the practice of learning engineering design in a studio environment much less of a necessity, simply because, in mechanical engineering, the making process is detached from the design process (Lyon, 2011). Also it is impractical for students to always validate their designs with physical prototypes limited by their abilities to manufacture; today it is much more appropriate that design validation also occurs through simulation and virtual prototyping. We must strike a balance between the use of physical prototypes and virtual prototypes in engineering design, and indeed a different emphasis on their use should be used to distinguish between the two engineering programmes. In a similar vein, the social context of the design studio could be replicated by on-line social media and communication - see Gooch and Medland (2003); altogether, a more appropriate preparation for a world where designers spend 50% of their time working on a computer (Robinson, 2012).

The practice-based approach allows both types of student to work collaboratively on the same project. Our challenge is to identify projects that will provide a range of problems with different levels of complexity that can be allocated appropriately to individuals. Whilst a team solution to the overall problem is required, different sub-systems should be created by each student using appropriately selected knowledge and design methods that reflect their qualification pathway and interest; we would expect the strategic approaches to design and the tools adopted to be different too.

4.5 Competency of the individual

The Bachelor of Engineering and Bachelor of Engineering Technology programmes fulfil the initial academic requirements of the engineering profession. Consequently the first degree is the most significant qualification demanded on the pathway to registration; therefore, it is essential that the competency of the student to design is assessed on an individual basis, particularly as design engineers will spend over a quarter of their time carrying out technical work alone (Robinson, 2012).

In practice-based learning, students should carry out individual design projects in which they are responsible for the creation of the whole solution but will also engage in team projects where they collaborate with others. It is essential in team projects that the role of the individual and their responsibilities to carry out specific tasks is clearly identified from the outset. Furthermore, the tasks they carry out must clearly align to the level and complexity their programme demands; this is particularly important where project teams involve students from the two programmes. We cannot allow the professional engineering student to avoid complexity and application of first principles in their work, nor should expect the engineering technologist to substitute. However, such collaborations provide an excellent learning opportunity by exposing the individual to the knowledge and capabilities of their fellow students and engaging them in a more complex system solution. Through reflection, it is feasible to assess not only what the student has learned through their own efforts, but also whether they have engaged in the overall process and understood what others have contributed and what knowledge and methods have been used to create the overall solution.

5 SO WHAT SHOULD WE TEACH MECHANICAL ENGINEERING DESIGNERS?

The engineering design educational approach we have described above sits alongside the papers in Engineering Science necessary to develop the student’s technical knowledge. We do not have the opportunity to discuss in detail the content of an engineering design curriculum in the this paper, but what is evident to us as teachers of engineering design is that there is a very deep knowledge base in our own Design Science beyond that which is just technical and associated with the types of design we are creating, i.e. engineering systems. Some Design Science is technical, but a lot is non-technical.

As discussed earlier, we believe it is necessary to present a rigorous theory of technical systems, e.g. as described by Hubka and Eder (1988) and Pahl et al. (2007), that enable students to describe the architecture and functionality of their solutions at all levels in the system. We need to provide rigour in the student’s formal understanding of the structure of a system, its sub-systems and individual parts, but also to guide them through its synthesis from first principles. We need to expose our students to Q-quality driven design (Robotham, 2000) with customer requirements captured through QFD and use Design for X to support lifecycle events and Design to X to improve the q-qualities of the product. Students also need to use standard parts, codes of practice, selection methods, fundamental principles of machine elements, materials selection, design optimisation, and economic decision making.

Similarly we need to embed a thorough understanding of the design process so that students can identify the tasks to be undertaken in their work and execute a coherent plan of action in a timely manner. The scope of the work undertaken will broaden through the programmes as the complexity of the projects undertaken evolves and focus is given to different design phases, i.e. concept, embodiment, and detail. Fortunately, there is an abundance of good quality literature available on the design process - our challenge is to provide a coherent and consistent process description.

Finally, it is not possible to expose students to the completeness of the Design Science, so we must develop them into active learners with an ability to explore and apply Design Science independently.

6 OUR THINKING EXPANDED INTO A LARGER CONTEXT

The discussion so far has focussed on the engineering design teaching within our undergraduate programmes. To conclude, we will briefly share some our thoughts in a larger context.

6.1 Project-led Undergraduate Engineering Programme

The project-led approach we favour is a defining characteristic of engineering design teaching but it has *not* been expanded to a programme-wide approach at undergraduate level; so why is this? Our commitment is to developing engineering graduates with a solid foundation in their discipline. The core technical knowledge base for mechanical engineering, the Engineering Science, includes applied mathematics, materials science, solid mechanics, dynamics, thermo-fluid mechanics, and control; these topics are, on the whole, new areas of study for our students and need to be thoroughly understood as they are the foundation for the design of technical systems. Engineering design needs to draw upon the student's Engineering Science and Design Science knowledge, Figure 4; as teachers of engineering design we need to have confidence that the problems we challenge our students with can be solved, more or less, with the Engineering Science already acquired.

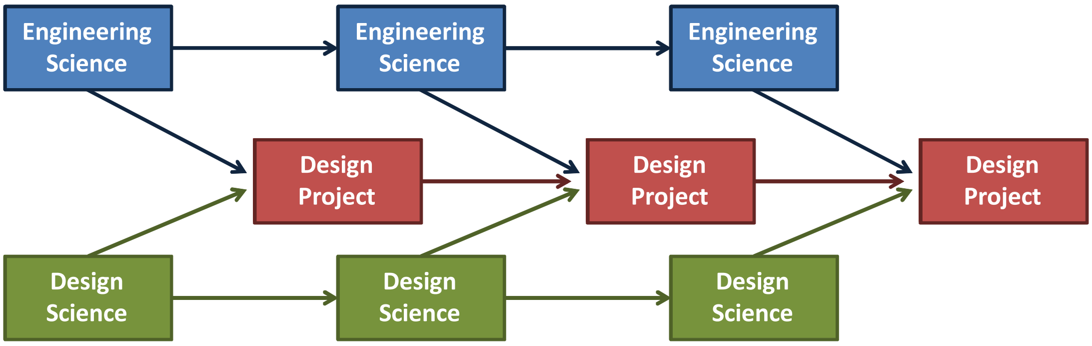

Figure 4: Design projects draw upon the Engineering Science and Design Science knowledge base

Naturally, a design project will throw up a need to acquire new knowledge, but essentially we need the fundamental Engineering Science to be known by the student from the outset. We have observed that where technical subjects have been taught in a project-led approach, then often only the knowledge specifically needed to create a technical solution was been delivered in the classroom. In such situations it then becomes difficult to evaluate whether graduates from the same programme would necessarily have (i) the completeness of knowledge, or (ii) the same knowledge demanded for professional registration. Whilst project-led teaching is essential in engineering design, it is less suited to teaching of analytical subjects. Nonetheless it is possible to reinforce certain analytical methods through the vehicle of a design project, e.g. a particular area of stress or vibration analysis, or optimisation techniques. We demand that our students draw upon both their Engineering Science and Design Science knowledge in design projects, and encourage our engineering science colleagues to adopt a 'designerly' way of problem solving in their teaching.

6.2 A Faculty wide Design Masters

Our description of the T-shaped engineering designer in Section 3 is a somewhat reduced version of the accepted understanding of T-shaped people. To be truly T-shaped, our engineering designers need to have a *'depth of skill to contribute to the creative process complemented by the disposition for collaboration across the disciplines'* and be *'specialists with a passion and empathy for people and for other subject areas'*, Hansen (2010). The need to develop T-shaped designers is understood in some national initiatives of design, e.g. UK (Design Council 2010), Denmark (Design 2020 Committee, 2011). Specifically, the UK Design Council (2010) noted that tomorrow's innovative companies need individuals that have had exposure to disciplines outside their individual specialisms, that have experience of working in teams with other disciplines, and that are comfortable deploying their innate creativity and flexibility within teams and projects.

Since the School of Engineering is part of the Faculty of Design and Creative Technologies, we have the opportunity to expose our engineering designers to other design disciplines and engage in inter-disciplinary design projects. To date, this has been an informal commitment, with a small number of individuals from, e.g. engineering and product design, working together on a final-year projects; it has not been a demand on every student on the programme. A more formal commitment to inter-disciplinary working has been made with the Bachelor of Creative Technologies, which combines knowledge from all the Schools in the Faculty - our concern here is that technically orientated graduates may not have the depth of Engineering Science knowledge to become registered engineers.

Our preferred option for developing our graduates into truly T-shaped designers is through an integrated, inter-disciplinary Masters level programme that draws in graduates from across the Faculty of Design and Creative Technologies as well as those from the sciences and business domains. Simon did propose that "the science of design" could form a fundamental, common ground of intellectual endeavour and communication across the arts, sciences and technology and that the study of design could be an interdisciplinary study accessible to all those involved in the creative activity of making the artificial world (from Cross, 2000).

The observed benefits of inter-disciplinary projects are that the learner does not function in isolation, but rather as part of the social group and environment they are located in; new knowledge is acquired from other students; develops not only an appreciation of the other disciplines, but also a renewed appreciation of their own discipline, learning style and identity (Lyon, 2010). Designers who have been taught on multi-disciplinary courses or have gained experience of working in multi-disciplinary teams develop a sought-after mix of skills e.g. business skills, broader knowledge of science and technology, and a better understanding of manufacturing and engineering (Design Council, 2010).

We would use a project-led approach to the programme, with an inter-disciplinary design project at the core of the curriculum. We would need to present a grand challenge to the students - a highly complex problem involving multiple stakeholders that demanded an original, innovative, technical and socio-economic solution, e.g. projects associated with regional/national/global challenges, infrastructure systems, climate change, an ageing population, or the need to find new and more sustainable forms of energy and methods of food production and distribution. We would expect the students to work collaboratively, whilst exercising their domain specific design expertise in prescribed roles in the team; they would also have the opportunity to deepen their own knowledge through research. Such projects would require considerable preparation beforehand to ensure the supporting resources were available and access to experts from academia, industry, and private and public sector services. We believe it would provide a platform for our Engineering Science colleagues to better understand the 'designerly' approach to problem solving.

We have not as yet created such a truly inter-disciplinary Masters programme nor developed the entry pathway for our engineering technologists, but we look forward to reporting our progress in the future.

6.3 Engineering Design Research

Engineering design research that would be recognised as contributing to Design Science has yet to be firmly established at Auckland University of Technology; we are often challenged that the nature of design research can be quite different from that of our engineering science colleagues, especially as many aspects of Design Science are non-technical. However, we are engineers in a Faculty of Design & Creative Technology where there are more academics of design than of engineering science! Consequently, we believe we have a better chance of developing a strong programme of engineering design research through working with our fellow designers. We are also guided by Cross (2000) who says that we do not have to turn design into an imitation of science – neither do we have to treat design as a mysterious, ineffable art. He also believes that normal works of practice can only be regarded as works of research if *"there is reflection by the practitioner on the work, and the communication of some validated and therefore re-usable results from that reflection"* (Cross, 2000). With this understanding, we see that we have an opportunity to contribute to engineering design research through observation and participation in the creative process of designing engineering systems.

7 CONCLUSIONS

We have discussed our experiences of engineering design teaching in the context of our bachelors programmes in Engineering and Engineering Technology. We have argued that we should develop T-shaped and t-shaped graduates, appreciating the differences in their chosen professional pathway. We have outlined the opportunity we have to engage students from both programmes on collaborative team projects where they learn by doing, and that such projects draw upon their Engineering Science and Design Science knowledge. We have argued that assessment should distinguish between product knowledge and process knowledge, and that the student's competency in both dimensions must be evaluated on an individual basis. Finally, we have identified that an inter-disciplinary, project-led Masters programme is the route to creating fully-formed T-shaped engineering designers.

REFERENCES

Cross, N. (2000) 'Design as a discipline', *Doctoral Education in Design: Foundations for the Future,* La Clusaz, France, 8-12 July 2000, UK, Staffordshire University Press, pp. 93-100.

Design Council (2010) *'Multi-disciplinary design education in the UK: Report and recommendations from the Multi-Disciplinary Design Network'*, London, UK, Design Council

Design 2020 Committee (2011) *'The Vision of the Danish Design 2020 Committee'*, Copenhagen, Denmark, Danish Enterprise & Construction Authority

Hansen, M.T. (2010) *'IDEO CEO Tim Brown: T-Shaped Stars: The Backbone of IDEO's Collaborative Culture'*, http://chiefexecutive.net/ (accessed 10th Jan 2013)

IPENZ (2010) *'Accreditation of Engineering Education Programmes',* www.ipenz.org.nz (accessed 7th Jan 2013)

Lyon, P. (2011) '*Design Education: Learning, Teaching and Researching Through Design'*, Farnham, Gower

Gooch, S. and Medland, T. (2003) 'Steps Towards Geographically Dispersed Collaborative Student Design Projects'. *2003 ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conference,* Chicago, IL, USA, 2-6 Sep 2003.

Hubka, V. and Eder, W. E. (1988) *'Theory of technical systems: a total concept theory for engineering design'*, New York, Springer-Verlag.

Hubka, V., and Eder, W.E. (1996) '*Design Science: Introduction to the Needs, Scope and Organization of Engineering Design Knowledge'*, London, Springer-Verlag,

Pahl, G., Beitz, W., Feldhusen, J. and Grote, K.H. (2007) *Engineering Design: A Systematic Approach*. Berlin, Springer.

Robinson, M. A. (2012). 'How design engineers spend their time: Job content and task satisfaction' *Design Studies,* vol. 33, no.4, pp. 391-425.

Robotham, A. (2000) 'The Chain of Quality through Integrated Product Development', in Rohatyński R. (eds) (2000) *2nd Int'l Seminar & Workshop on Engineering Design in Integrated Product Development - EDIProD 2000,* Technical University of Zielona Góra, Poland.

Shaw, L. (2002). Learning for Life: The Origins of Auckland University of Technology. Auckland University of Technology.