Renewing Mechanical and Mechatronics Programs

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Introduction

This paper discusses the on-going work to prepare new programs in mechanical and mechatronics engineering at the University of Technology Sydney, taking into account complex problems on the one hand and emerging educational technologies and pedagogies on the other.

The paper serves as a roadmap for similar transformations elsewhere. In many ways, curriculum design is not the major issue. Curriculum *change* is the major issue, first for our academic staff who are used to teaching in a particular way, and second for our students, who are often comfortable with an exam-driven system that does not serve them well in the long-term. Learning the standard solutions of the past does not prepare a graduate to invent new solutions for a changing, complex future.

The paper is of obvious interest to those in related disciplines, as they make their own curriculum revisions for a world with rapidly changing industry needs. However, the paper should be of interest to those in other disciplines (not just engineering) because it signposts the *processes* we have used to explore future graduate capabilities from industry, with input from both students and academics, in the nature of the future curriculum.

A studio-based curriculum is proposed, with many examples of suitable studio projects generated by industry, academics and students.

The 21st century is a time of great change, with job automation and offshoring now overtaking the professions, including engineering and information technology (Friedman 2006). The professional jobs that are remaining are those that require creative responses to complex problems, and/or with high human contact (Institute for the Future 2015). Therefore, as university educators, we need to prepare graduates for this new world, including the ability for graduates to start and build their own organisations.

We believe that, to achieve this, learning needs to be much more experiential, based on projects and studios as well as internships, global mobility and other experiential extracurricular activities (Prince 2004, Prince and Felder 2006, Hadgraft, Prior et al. 2016, Hadgraft, Francis et al. 2018). A studio combines project-based learning with student-led learning, enabling each student in the studio to develop themselves according to their own learning/career plan. The evidence of learning for each student will be their *learning portfolio*.

This form of collaborative learning builds competencies, teaches creativity, and how to deal with complexity. As academics, we also need to model these capabilities.

Andreas Schleicher, OECD Director for Education and Skills, reminded us that the modern world no longer rewards people just for what they know but for what they can do with what they know (Schleicher 2018).

Researchers can attest to the value of this kind of learning in terms of educational attainment. Angela Duckworth's *grit* (combination of perseverance and passion) and Carol Dweck's *growth mindset* show causal links to improved performance (Better than Yesterday 2016, Duckworth 2017, Dweck 2017).

Further, many reviews of engineering education in the last 15-20 years have urged transformation of engineering education (National Academy of Engineering 2004, National Academy of Engineering 2005, Spinks, Silburn et al. 2006, King 2008, Sheppard, Macatangay et al. 2008, Carnegie Foundation for the Advancement of Teaching 2009, Beanland and Hadgraft 2014, Institute for the Future 2015).

These international reviews recommended several issues to be addressed such as: the ability to deal with complex problems, interdisciplinarity, creativity and invention, leadership, sustainability, global ethics, and lifelong learning (Hadgraft 2017). Curriculum changes suggested included: a professional spine, teaching for connection between topics, approximate engineering practice, use case studies, situate problems in the world. The Henley Report (Spinks, Silburn et al. 2006) recommended three different kinds of engineers: the technical specialist, the integrator and the change agent.

How might we achieve these recommendations, given the evidence of change over the last 15-20 years is scant? Our solution is a curriculum built around studios, borrowing from the design disciplines (Studio Teaching Project Team 2015).

About Studios

Capabilities developed in studio learning include grit, resilience, growth mindset, curiosity, collaboration, communication, creativity and sensitivity to sustainability and global concerns. Graduates need an agility of mind and transferable skills to meet future skill needs and give back to their communities.

Studio facilitators work beyond the role of imparting knowledge: they are coaches, critics and expert learners. Feedback loops are critical in studios, with students and educators providing regular feedback to one another to achieve quality learning. Education Professor, John Hattie, reminds us that the biggest effects on student learning occur when teachers become learners of their own teaching, and when students become their own teachers (Hattie 2009). Students in studios have the flexibility to engage in hands-on activities.

The aim of studios is to prepare students for a lifetime of creating new solutions and thriving in a fast-changing world. Traditional subjects are complemented with real-world problems where students can apply their knowledge to collaborative problem-defining and creative problem-solving using and learning both technical rationale and professional capabilities.

Studios in FEIT

As early as 2014, studios have been used in software engineering to immerse students in real projects with industry partners (Prior, Connor et al. 2014, Prior, Ferguson et al. 2016). These studios were initially extracurricular, with students able to use work they were doing in the studios as replacement assessment tasks in their formal subjects.

From 2015, it was decided to integrate studios into all of the programs in the Faculty, both engineering and IT. The first discipline was Data Engineering, a new program that replaced the former ICT (Information and Communication Technology) Engineering program. This launched in 2017 (Hadgraft, Prior et al. 2016, Hadgraft, Francis et al. 2017). Electronic engineering followed in 2018 and electrical engineering in 2019. Mechanical and mechatronics programs will launch in 2020 with civil engineering in 2021.

Why Studios?

Engineering and Information Technologists use design processes to solve complex problems and to develop new product opportunities (Petroski 1996, Cross 2000, Dym and Little 2008). The Faculty's new *Graduate Attributes,* adapted from (Cameron and Hadgraft 2010), embody the capabilities necessary for professional practice. A graduate is expected to be able to:

A. Be historically and culturally informed about *Indigenous knowledge systems*
B. Be *socially responsible*
C. Use a systematic *design* process,
D. Apply disciplinary *technical skills*,

E. *Communicate* and *coordinate* tasks with co-workers,
F. *Self-manage* tasks, projects and career development.

Although there has been a history of project-based learning in the Faculty for many years, we are now planning to take this to the next level, shifting the emphasis from Projects to Student Learning. Studios embody that shift (Hadgraft, Prior et al. 2016).

Studios provide students with project opportunities to develop the full range of professional capabilities [A-D]. Students work collaboratively [E] and are responsible for their own learning, as defined in a learning contract. Their learning and contribution to the project are documented in a personal *e-portfolio* [F].

The studio is the *vehicle* for each individual's learning, as part of their overall career development at the university. Their personal e-portfolio is a record of their achievement of the graduate capabilities and of their readiness to step into the world of work. It will contain many examples that might be discussed at a job interview, demonstrating the graduate is work-ready.

The University Background

This University is committed to produce graduates who (UTS 2014) are equipped for **ongoing learning and inquiry**, have accumulated a **body of knowledge** for professional practice and are committed to the actions and responsibilities of a **professional and global citizen**.

To formalise these ideas, in late 2014, the University articulated the ***Learning.Futures*** model of learning comprised of (UTS 2015), which emphasises practice-based education for a **global workplace**, based on learning that is **research-inspired.**

Learning.Futures, however, has mandated key shifts in *classroom practice*, requiring learning that is active and collaborative, based on authentic problems (practice-based), using blended or flipped learning to make the most of available learning resources.

The Faculty Context

The Faculty of Engineering and Information Technology has a long history of engagement with practice-based learning (Parr, Yates et al. 1997). Within learning and teaching, our intent is to provide a **flexible, practice-oriented, and inclusive learning environment** that integrates **innovation and entrepreneurship with a f**ocus on **transdisciplinary approaches** and the science of engineering.

The challenge is to enact this fine rhetoric! The remainder of the paper sets out the process we have used in designing our new programs, specifically, the mechanical and mechatronics engineering programs. As Stephen Covey says: "begin with the end in mind" (Covey 1989).

Consultation

Step 1: Industry

At the November 2016 Program Advisory Board meeting, we laid the foundation for revising the mechanical and mechatronics engineering programs. Four key questions were addressed: *global trends*, the changing *nature of work* and *projects*, the kinds of *capabilities* required in this changing environment, and the kinds of *graduates* for the future.

Among the 18 industry representatives at the meeting there was collective agreement that skills that the university should provide included:

1. 'hard' competencies such as: costing; contracts; commercial/legal/regulatory; designing to specification; hands-on, prototyping skills
2. 'soft' skills: confidence; critical thinking; arguing your case; persistence; remote communication; customer centricity; teamwork and leadership; interpersonal skills

Step 2: Students

A small group of student representatives also provided input during 2017. They saw positives in the old, more traditional approach as one that's familiar, coming from high school. They recognised that the current design and build subjects were helpful (Introduction to Mechanical Engineering and Mechanical Design) with a hands-on approach in some other subjects (e.g., Manufacturing Engineering, Advanced Manufacturing).

They saw negatives in the old curriculum, which they saw as not as hands-on as students are led to believe. Hands on workshop time is also lacking. Design philosophy is not well implemented in most subjects. The degree as it is, is not a realistic representation of real-world engineering.

They saw the positives of a new project-based, studio-based curriculum as modelling real-world mindset for engineering: learn the fundamentals first and develop advanced skills when necessary for completion of projects, maybe with the assistance of online modules. Academics should mentor students in the projects as required. This mentorship is what happens in engineering workplaces; why not start at university?

Overall, students found that a new project-based curriculum would benefit students significantly more than the current system.

Step 3: Staff input

In January this year, a staff meeting sought to gather input from as many of the staff (academic, technical, administrative) as possible, using the themes of: Trends, Strengths, Methods, Concerns, and Opportunities.

The discussion of **Trends** affecting mechanical and mechatronics engineering quickly opened up the breadth of the challenges and opportunities for these disciplines – safety, robotics, energy systems, autonomous vehicles, data-driven systems, Internet of Things, and environmental sustainability. The breadth of these challenges highlights the difficulty of designing mechanical and mechatronics programs to enable graduates to move into any of these fields:

Our teaching **Strengths** were seen to be well aligned with the proposed direction for more studio-based programs. It was felt that student interaction is already structured to provide a reason to come to campus/class/lab (with room for improvement). There are small group, face-to-face learning activities, supported by blended learning in a friendly environment. This is the essence of Learning.Futures (above). Academics endeavour to provide constructive feedback and offer many teamwork activities in which time management skills, critical thinking, and independent learning is encouraged.

Graduate employability is at the forefront of curriculum intentions across the University. (This Faculty has an internship program that gives all single degree students 2 x 6-month industry placements during their degree). Industrially relevant projects and hands-on practical, active learning joins theory and practice.

Sample curriculum design

The current mechanical engineering program runs over 10 semesters, including two, 6-month work placements (Figure 1). This figure has been colour-coded to indicate mathematics subjects (pink), thermofluids (green), materials (blue), management (brown), machines (grey), potential design and project subjects (yellow), and electives/sub-major (white). Subject names are in **bold** and pre-requisites are in *italics*.

We have experimented with both 6 and 12 credit point studios. This paper presents a combination of 6cp and 12 cp studios, where subdisciplines have been given at least one 6 cp introductory subject plus a 12 cp studio. The introductory subjects are effectively the core, and the studios become options (Figure 2).

Introductory concepts in mechanical and mechatronics are established in the first two studio subjects in stages 1 and 2 (first year), augmented by introductory subjects in Statics and Solid Mechanics, Materials and Manufacturing and Engineering computations.

In stage 3, students take Thermofluids and Machine Element Design in conjunction with Studio A, where they now have a basic body of knowledge across much of mechanical engineering.

Students are then setup to undertake 4 out of 5 elective studios over the next 4 semesters, with their capstone project in the final semester. Topics include:

1. solid mechanics (e.g. FEA and other advanced computational tools)
2. machine design, mechanical vibration and measurement
3. advanced manufacturing
4. fluid mechanics and computational fluid dynamics
5. thermodynamics, heat transfer, power and refrigeration cycles
6. pneumatic and hydraulic control and design

There are two ‘selective’ slots where students choose additional subject to prepare them for some of the studios. (This enables some studios to require an additional preparation subject).

Students have 4 additional general electives, which could be used to undertake another studio-selective combo and/or additional depending subjects, drawing also from the pool of postgraduate subjects. Students may also take broadening subjects, e.g. in business, engineering management, data analytics, etc.

Stage 1	Stage 2	Summer	Stage 3	Stage 4 Summer	Stage 5	Stage 6	Summer	Stage 7	Stage 8	Summer Stage 9	Stage 10
Mathematical modelling 1	Mathematical Modelling 2		Engineering Commuptations	Engineering Experience 1	Fluid Mechanics	Thermodynamics		Heat Transfer	Engineering Research Preparation	Engineering Experience 2	Engineering Capstone
Physical modelling	Chemistry and Materials Science		Mechanics of Solids		Strenth of Engineering Materials	Engineering Economics and Finance		Engineering Project Management	Entrepreneur-ship and Commercial-isation		Sub-Major/Elective
Engineering Communications	Introduction to Electrical and Electronic Engineering		Manufacturing Engineering		Machine Dynamics	Dynamics and Control		Mechanical Vibration and Measurement	Sub-Major/Elective		Sub-Major/Elective
Introduction to Mechanical and Mechatronic Engineering	Fundamentals of Mechanical Engineering		Design and Innovation Fundamentals		Mechanical Design 1	Mechanical Design		Advanced Manufacturing	Mechanical and Mechatronic Design		Sub-Major/Elective
			Engineering Practice Preparation 1		Engineering Practice Reflection 1				Engineering Practice Preparation 2		Engineering Practice Reflection 2

Figure 1: Current mechanical engineering program

First Year			Second Year		Third Year			Fourth Year			Fifth Year
Autumn	Spring	Summer	Autumn	Spring Summer	Autumn	Spring	Summer	Autumn	Spring	Summer Autumn	Spring
Stage 1	Stage 2		Stage 3	Stage 4	Stage 5	Stage 6		Stage 7	Stage 8	Stage 9	Stage 10
Mathematical modelling 1	Engineering computations and modelling		Mathematical Modelling 2	Engineering Experience 1	Design and Innovation Fundamentals	Engineering Economics and Finance		Engineering Project Management	Engineering Research Preparation	Engineering Experience 2	Engineering Capstone
Physical modelling	Statics and Solid Mechanics		Thermofluids		Machine dynamics	Selective 1		Selective 2	Sub-Major/Elective		Sub-Major/Elective
Engineering Communications	Materials and Manufacturing		Machine element design		Mech and Mx Studio B	Mech and Mx Studio C		Mech and Mx Studio D	Mech and Mx Studio E		Sub-Major/Elective
Introduction to Mechanical Engineering	Introduction to Mechatronic Engineering		Mech and Mx Studio A								Sub-Major/Elective
			Engineering Practice Preparation 1		Engineering Practice Reflection 1				Engineering Practice Preparation 2		Engineering Practice Reflection 2

Figure 2: A proposed studio model for mechanical engineering

Figure 2 represents a stretch target for curriculum change. Many of the technical subjects have been retained, while a strong, integrating design/studio thread has been established. Note that both Engineering Communication (Eng Comm) and the two Introduction to Mechanical/Mechatronic Engineering subjects establish the basic collaboration and design skills required for the subsequent studio subjects, which then lead to the Capstone Project as an individual investigation. Students begin to engineer from the first semester, gradually developing their design and investigation skills through each project/studio, documented in their portfolio. This is a design-based curriculum rather than an analysis-based one.

Conclusions

Curriculum transformation is difficult. We have applied design thinking to the process and engaged our key stakeholders – industry friends, students and staff. Key questions for our industry supporters have included: what are the big trends affecting your company? How is the nature of work changing? What capabilities will graduates need in your new workplace?

We have asked our students to identify positives and negatives of our existing programs and teaching methods and also to review some proposed studio/project-driven curricula.

Our academics have also identified trends in the discipline and strengths within the existing academic team and organisation (the School and the Faculty). This process enabled them to see that we are already well-equipped to implement a project-based curriculum. The major challenges will be to provide suitable supervision, feedback and assessment in classes of 150-200. This is the next stage of our development work.

The stakeholder engagement described here is more than just collecting ideas and drafting a new curriculum. In many ways, that's the easy part of the work. The conversations and workshops have been critical in building consensus and enthusiasm for change.

We have also run summer studios in the last two years as experimental opportunities for academics to test the studio concept with small numbers of students (10-25) before they embark on classes of 10 times that number. Lessons from those studios are documented elsewhere (Hadgraft, Francis et al. 2018).

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