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Engineering Capstone Curriculum Design – Reflections of a Design Team

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ABSTRACT

CONTEXT

The engineering capstone is often regarded as the pinnacle of undergraduate engineering studies. Students are expected to learn about engineering challenges, demonstrate the knowledge they have acquired throughout their engineering studies, and be able to transition to the engineering workplace. The challenge is how to translate this experience into a learning design.

PURPOSE OR GOAL

This paper serves as a reflection on a learning design and teaching practice that has reshaped the "capstone learning experience at a technical university in Australia. The paper presents the "sociology" and rationality underpinning an attempt to apply Universal Design for Learning (UDL) model to capstone curriculum development.

APPROACH OR METHODOLOGY/METHODS

This paper presents preliminary observations of a collaborative autoethnography study (CAE) of a team of academics dedicated to the design and redesign of Capstone units of study at a technical university in Australia since 2022. This curriculum design process entails the continuous development and improvement of capstone pedagogy, assessment, and mobilisation of resources to design and maintain the "infrastructure" of engineering capstone subjects.

ACTUAL OR ANTICIPATED OUTCOMES

This study reveals the actual process of a capstone curriculum development process. The designers realized that the challenges of capstone curriculum design lie in several mismatches of the actual student learning experience with an established UDL model. A preliminary analysis is undertaken to guide future practice.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The designers realized that the capstone does not fit with the current underlying structure of the engineering curriculum. An icebreaker approach could be fostering diversity of capstone projects. However, the challenge is to provide scope for building students' research practices, and to provide the language to discuss research as an engineering practice.

KEYWORDS

Engineering Capstone, Curriculum Design, Collaborative Autoethnography

Introduction

The landscape of teaching and learning in higher education has shifted in recent years, encouraging complex problem solving and requiring educators and students to switch to remote teaching and learning in a very short space of time. This has led to changes in learning expectations, learning outcomes, and teaching and learning practices. One shift concerns students' preparedness to engage in research projects and in face-to-face in-class activities, particularly impacting the learning design and teaching practice of engineering capstone subjects. The engineering capstone project is the major engineering project experience required for an engineering honours degree for professional engineers (EA, 2008), and is often regarded as the pinnacle of undergraduate engineering studies. The capstone project is a research project that follows a typical design process, from ideation to final product/presentation. Through the experience of completing the capstone, students are expected to learn about engineering challenges, demonstrate the knowledge they have acquired throughout their engineering studies, and be able to transition to the engineering workplace (Shurin, Davidovitch, & Shoval, 2020).

In Australia, academic publications on undergraduate capstone learning design focus on pedagogy and assessments (e.g., French et al., 2015; Hammer et al., 2018; Knudson et al., 2019; Lawson et al., 2015; Lee & Loton, 2019, Willey et al., 2008). There is less focus on the curriculum design that underlies the capstone project, and less still on the research practices that are assumed to be developed in the undertaking of the project. At our university, as with other Australian universities, the capstone project is part of an embedded honours degree in Engineering. Thus, it is required to develop research capabilities in line with The Australian Qualifications Framework (AQF) level 8 Honours degree (AQF, 2013).

This paper serves as a reflection on a learning design and teaching practice that has reshaped the "post-pandemic" capstone learning experience at a technical university in Australia. The context in which this re-designing effort is taking place is that recently, students have become more accustomed to technology-enhanced remote learning, while some of our colleagues are trying to maintain the value of in-class activities. This tension has given the engineering capstone team an opportunity to combine engineering and learning design thinking to create a hybrid learning experience for capstone students.

Literature Review

Much of the literature on higher education curriculum review focuses on institutional processes and procedures (Bajada, Kandlbinder and Trayler, 2019; Khan & Law, 2015; Meyer & Bushney, 2008). The findings recommend curriculum reviewers attend to internal institutional factors such as leadership, management, and staff goodwill, and external factors such as regulatory requirements, external stakeholders, and professional memberships (Bajada, Kandlbinder & Trayler, 2019). Generic stages of curriculum review are identified: market analysis, curriculum planning, learning program design and development, delivery, assessment, and program evaluation (Meyer & Bushney, 2008). The findings exhort reviewers to think of core-curricular dimensions such as the hard skills and the disciplinary education of a specialist, and co-curricular dimensions such as professional skills and more generalist education (Khan & Law, 2015).

Common also in the literature is a framing of higher education curriculum as being in the service of industry (Nygaard, Hojlt, & Hermanesa, 2008). This framing is seldom subjected to interrogation. Studies frequently rehearse descriptions of rapidly changing technology and the need for higher education to relentlessly pivot and respond to exigencies in the economy (Palacin-Silva, Khakurel, Happonen, Hynninen & Porras, 2017). Clegg (2009) characterises this as a fracturing of the meaning of higher education, reducing research to a commodity, and education to employability.

Less common in the literature are explorations of the personal experiences of curriculum developers. Curriculum development as documented in the literature has a very procedural flavour and does not capture the discussions that underpin the iterative and often messy process of curriculum development. Peseta (2005) observes that the conceptual tools used in curriculum development are not well-suited for capturing difficult experiences such as frustration, guilt, or shame, or even the positive experiences of pleasure or joy that usually accompany curriculum review.

Unlike most curriculum design, which tends not to acknowledge differences in students' approaches to learning, Universal Design for Learning (UDL) recognises that there are wide variations in how students respond to instruction (CAST, 2018). UDL has three central principles for curriculum design that addresses the why, what, and how of learning:

- Multiple modes of student engagement that tap into learners' interests, challenge them appropriately and motivate them to learn
- Multiple methods of representation that give learners a variety of ways to acquire information and build knowledge
- Multiple means of student action and expression that provide learners with alternatives for demonstrating what they have learned (UNSW, 2023).

These principles provide opportunities for curriculum designers to build in flexibility in teaching and learning activities that accommodate students' diverse interests, needs and learning approaches. Using UDL as a theoretical framework can enable the development of a curriculum that responds to learners' needs and leads to greater student motivation, thus resulting in a more meaningful learning experience.

Methodology

This research is inspired by Latour and Woolgar's (1979) ethnographic study of the social construction of scientific facts and Bucciarelli's (1994) participant observation study on engineering design in industrial companies. Both studies adopt an ethnographic approach to studying scientific research and engineering design practices. These studies established the theoretical foundation of seeing engineering curriculum design as a social process, because even technical processes are intrinsically social. This paper presents preliminary observations of a collaborative autoethnography study (CAE) of a team of academics dedicated to the design and redesign of Capstone units of study at a technical university in Australia since 2022. This curriculum design process entails the continuous development and improvement of capstone pedagogy, assessment, mobilisation of resources, in general, designing and maintaining the "infrastructure" of engineering capstone subjects.

Curriculum development and improvement are complex (Hicks, 2018; Baradell et al., 2018). Because of the number and diversity of stakeholders involved in the Capstone projects, Capstone units of study design and development are equivalent to the complexities of program-level design. Due to these complexities, the capstone curriculum design is undertaken and maintained by a team of academics at this university.

In this paper, the authors have differentiated between the theoretical framework used for curriculum design and how the authors have reflected on the design process. The theoretical framework which guides capstone curriculum design activities is an adaptation of the Universal Design for Learning (UDL) model (CAST, 2018; Meyer et al., 2014)

The reflection on the design process - a social process - follows a collaborative autoethnography (CAE) approach. Collaborative autoethnography as a research method emerged from autoethnography, an autobiographical genre of academic writing that draws on and analyses or interprets the lived experience of the author and connects researcher insights to self-identity" and a wide range of social and cultural issues (Adams, Jones & Ellis, 2015, p.2). CAE is "a qualitative research method that is simultaneously collaborative, autobiographical, and ethnographic" (Chang et al., 2016, p. 17). CAE is often used to give meaning to a social phenomenon with self-reflections of a "cultural group" (Chang et al., 2016), thus allowing all the voices of the researchers to be heard. Capstone curriculum design is a social phenomenon. Hence, its process can be viewed by its designers within a broader higher educational context. Designers' self-reflections can capture richer data than simply a review of a linear design process, because self-reflections are more nuanced and can include more profound perceptions and incentives from different positions, a diverse "cultural group". Self-reflections are the data to support the analysis of this study, leading to an attempt to respond to the central research question "How should we provide a meaningful learning experience to engineering capstone students?".

Capstone Designers as a Cultural Group

The capstone units of study are co-coordinated by two academics Dr J and Dr K, in collaboration with Dr G., the faculty research literacy consultant. Dr J was trained as a professional engineer, Dr K received a PhD degree in education, and Dr G. has a PhD in engineering education. Dr J and Dr. K's coordination role coincided with a change in faculty's approach to the assessment of capstone units of study. This change was from an assessment of the deliverables - the submissions - towards a more comprehensive evaluation of student performance during the lifecycle of a project. This continues to be a work in progress. The initial division of labour between these two subject coordinators was that Dr J focused on the assessment mechanism for the evaluation of an engineering project and Dr K developed learning activities centred on the engineering experience. The outcome of this cooperation was an update to the assessment criteria of the capstone that depicts key features of project execution and interpretation of competency development.

The second shift of the capstone curriculum took place when Dr G joined the designer team, first, as an academic literacy expert. At that moment, a discourse, if not a debate, emerged at the faculty level, trying to determine whether "research methodology" is an essential part of teaching in the preparation phase of the capstone. Importantly, what does "research methodology" mean to engineering students? It was, perhaps, due to Dr G's emphasis on academic literacy, insisting that student work should fall into an established research paradigm, that the debate reached its closure. In the meantime, this small team decided to adopt UDL as the steering concept of capstone curriculum design.

The latest change, or change cycle, for the capstone curriculum, was triggered by the streamlining of the engineering units of study of which capstone is a part. The guiding principle of this transformation lies in creating lean processes of capstone administration. The administration process entails student and supervisor matching mechanisms, project-related administrative affairs such as project health and safety, ethics approvals, and organising project showcases. Changes to these seemingly academically peripheral affairs bring in larger scales of stakeholder engagement of the capstone. It was on this occasion, Dr A and Dr C joined the capstone curriculum design team. Dr A and Dr C have engineering backgrounds, and they have academic leadership roles in the faculty.

There is a consensus, which serves as a cultural foundation, in this curriculum design team that the capstone provides engineering students with a major project experience through which the human dimensions of engineering can be practised.

Capstone Stakeholders and the Sociology of Curriculum Design

At this technical university, the capstone curriculum design is not just a configuration of a learning program - syllabus - that assemble teaching and learning activities with assessment tasks. The basic design of the capstone curriculum is to define three pairs of relationships namely, student-supervisor relationship, student-service relationship, and academic-industry relationship.

From a sociological perspective, teaching and learning activities in the capstone subjects can be briefed as developing and maintaining student-supervisor relationships. This includes students doing research under the supervision of academics, assessments of student performance, and in general a collective problem-solving process. The role of capstone curriculum designers is infused within the entire process. The most significant input of the capstone coordinators is to liaise supervision resources across schools and entities. This liaison activity often takes place at the school-level teaching and learning meetings. The subject coordinators are also involved in the development of an online platform on which students are matched with supervisors by various means. This part of the capstone subject coordination responsibility differentiates the capstone coordinator from the coordinators of other units of study.

The student-service relationship, in the capstone, refers to student access to university services and facilities that enable the execution of the project. Essential services include access to databases and references from the library, access to laboratories, devices, and computer software. To incorporate these services, workplace health, safety, and research ethics approval procedures have been established and embedded in the student and supervisor communication channel. The capstone coordinator's role is to ensure that the capstone as an educational project is compatible with existing university regulations. Capstone students and supervisors also contribute to the quality of services provided to future students in the sense that a collection of capstone reports in the university library serves as a source of inspiration.

The academic-industry relationship manifested in the capstone project appears in two ways. On the one hand, the faculty encourages students to bring in real-life engineering problems as their capstone projects. On the other hand, some industrial partners take the capstone as a channel to maintain a stronger tie with the academic community which may assist their technological and marketing development strategies. In fact, this type of academic-industry relationship can be regarded as a student-industry relationship. In this faculty, student-industry engagement is rendered in a capstone project showcase taking place every semester. Although capstone coordinators have indirect engagement with industry partners, mainly through the business relationship officer at the faculty level, the organisation of the showcase requires input from the capstone coordinators.

When the designers finished the capstone redesign and started implementing the units of study, they came to the realization that the capstone did not fit: the students' research capabilities that the capstone project was intended to assure, were in many cases underdeveloped. This led us to investigate where the gaps might be occurring, or where the opportunities to develop research capabilities were missing.

Such a mismatch also appears in the alignment of EA stage 1 competency standard with AQF Level 8 descriptors, in terms of the perception toward the "nature" of engineering capstone. What can be inferred from the EA requirements is that the Capstone shall provide students with a major engineering project experience in which students shall make technical decisions to solve a complex engineering problem. Although, research competency is listed as a key to some professional engineering practice, it may not be an essential component of the Capstone. The Australian Qualification Framework (2013, January 1) descriptors indicate a stronger research orientation toward capstone in the sense that students shall be able to shape "well-developed judgments". From a professional perspective, such judgments come from a profound understanding of the problem which should be constructed upon research,

Figure 1 summarises the sociology of the capstone curriculum design.

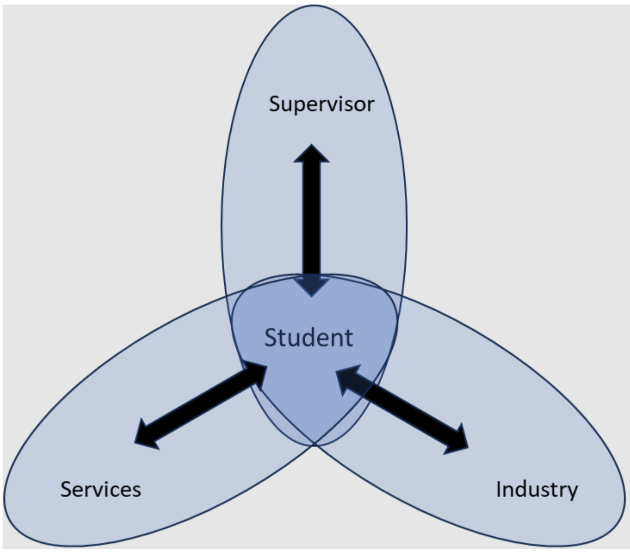

Figure 1 Stakeholders of Capstone Curriculum Design

The Capstone Infrastructure

In addition to the mapping of stakeholders involved in the capstone experience, the conceptual design of the capstone curriculum derives from collective observations of student performance and reviewing assessment tasks. In the faculty, research-oriented type of Capstone curriculum design is an attempt to align EA stage 1 competency standard and AQF descriptors of an honours degree, AQF8 (AQF, 2013). As a result, Capstone projects can be categorized into scientific research in which students undertake literature-based or experiment-based study, engineering design in which students undertake a prototype design or a design modification to improve the functionality of an engineering system, and "social research" relating to engineering practice, management, and education. These orientations are compatible with Engineers Australia Stage 1 Competency Standards in role descriptions.

> *"Professional Engineers may conduct research concerned with advancing the science of engineering and with developing new principles and technologies within a broad engineering discipline. Alternatively, they may contribute to continual improvement in the practice of engineering, and in devising and updating the codes and standards that govern it." (EA, 2013, para. 3)*

In this respect, the UDL model for curriculum design can be interpreted in the capstone context as the following:

Table 1. Adaptation of UDL for Capstone Curriculum Design

	Engagement	**Representation**	**Action & Expression**
Access (Manifestation)	Public and the society Capstone Showcase	Academic community Capstone Showcase	Industry partners Capstone Showcase
Build (Methodologies)	Social research methodologies	Scientific paradigms	Systematic engineering design
Internalise (Aspects of Competencies)	The human side of engineering	The scientific foundation of engineering	Research and development

Goal (Types of Projects)	Engineering practice, management, and education • Continuous improvement of Engineering practice • Engineering as a service for the society	Engineering Science • Advancing understanding of engineering science • Developing technologies for scientific discovery	Engineering Design • Technology innovation • Improving functionality • Developing new systems

Table 1 demonstrates the adaptation of the UDL model to capstone curriculum design with the types of projects as the goal of student learning. As the type of project differs, student competencies development through project experience varies. Students who work on engineering design projects leverage design competencies. Scientific projects strengthen students' skills in scientific research. Students interested in engineering practice and education are trained through the capstone project on how to engage in society with engineering capabilities. Competencies are developed, in the UDL term “built’, with appropriate methodologies, quantitative, qualitative, or hybrid mode. The capstone showcase is the channel for capstone projects to be manifested to the audience that expressed diversified interests. As a result, the capstone curriculum design provides three pathways to achieving meaningful student experiences.

Findings and Discussions

The above two sections present the curriculum design process as if it follows a linear approach. The actual process, from the designers’ reflective journals, reveals a different storyline. The UDL model predicts a linear and top-down process, at least in the early stages of curriculum design. In this regard, as presented in Table. 1, the educational goals, learning outcomes, and pedagogies should be determined at the early stage of curriculum design. But, in this case, as it is implied in the capstone designers’ section, the conceptual design stage took several years of evolution. The actual conceptual design is achieved layer by layer. The first layer clarified was the “internalise” layer with a collaboration of engineering practice academics. The next breakthrough was the “build” layer at which research methodology teaching for engineering students was defined. This refers to a collection of options that give guidance on problem definition, data collection, and analysis for social research as one stream, experimental design, and systematic engineering design as the other two streams. The foundation layer, “goal” was confirmed and re-affirmed within each change cycle. The “Access” layer has always been an existing layer because the capstone showcase is a traditional event each semester. In retrospect, the actual curriculum design and development process is iterative and accumulative rather than straightforwardly linear.

Another mismatch that can be identified is the stakeholder analysis as represented in Figure 1. This shows the adaptation of the UDL model to the capstone curriculum, in that the presumption of the adaptation model is that students are clear about their directions and pathways. In reality, a sense of direction is developed with the supervisor. On the surface, this mismatch is often manifested in capstone teaching and learning as a mismatch of student expectations and requirements of learning outcomes, especially in transdisciplinary topics. In-depth, this may lead to some profound questions concerning capstone-like, project-based learning, subjects, such as “Should supervisors be trained as well?” and “How can we encourage supervisors to see their role as educators rather than as overseers?”.

At the subject teaching and learning design level, questions as such are in fact the challenges to impact student experience. This may also explain why the actual curriculum design process does not follow a top-down, linear flow.

Conclusions

Capstone experience entails research content. Although the capstone subjects are designed with an intent to provide students with a chance to resolve a complex engineering problem , we realized that student ownership of the capstone project needs to be cultivated. This leads to a question beyond the discourse of developing engineering professional competencies. The sense of ownership resembles consciousness in research literacy in that the capstone experience contributes to knowledge-making. A gap of consciousness as such seems to be obvious from our reflections. What we have learned from our attempts to apply UDL to the capstone units of study is that not only an infrastructure of learning is needed but also the educational sense of the capstone project needs to be demonstrated in more explicit terms. In this paper, we tend to propose that research literacy may be the essence.

We realized the capstone does not fit with the current underlying structure of the engineering curriculum, which is dominated by a focus on the acquisition of technical knowledge. This focus does not provide scope for building students' research practices, nor does it provide the language to discuss research as an engineering practice. Problem-solving seems to be too narrowly defined as providing technical solutions to a technical problem rather than an appropriate response to a complex problem.

Our experience and reflections remind us of fostering diversity of Capstone projects as research may be a response. e challenge that confronts us is the missing research as practice in the engineering curriculum: not just an absence, but something that should be present and is not, or is present but invisible.

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