Integrated Engineering may be necessary, but perhaps design would be taken more seriously

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SESSION

S1: Is Integrated Engineering Education Necessary?

CONTEXT

Integrated Engineering (IE) units have been introduced in engineering programs to address the practice-based aspects of engineering including the development of professional skills, such as communication and team work. At one large university in Australia, IE is expected to teach content perceived as non-engineering or not directly relevant to the technical aspects of engineering which includes written communication skills, ethics and recently introduced graduate attributes, such as cultural competence and interdisciplinarity. Feedback from tutors and students is that IE is not directly relevant to their studies. The perceptions and feedback has prompted questions as is whether IE is the only unit to develop these skills, whether they could be developed elsewhere in the curriculum, and what is it about developing these skills, particularly cultural competence, that is resisted.

PURPOSE

The aim therefore is to review the literature to understand how the skills could be embedded within engineering curricula to help determine whether IE is indeed necessary. The focus is on cultural competence as it appears more challenging than other skill areas to incorporate.

APPROACH

A literature review was conducted and involved identifying conceptions of cultural competence, engineering, and design. The review was expanded beyond engineering to include education, business ethics, social psychology to better understand the concepts identified.

RESULTS

The results of the review are that curriculum influences learning and what is valued or what is interpreted as relevant. Adding IE to a conventional curriculum may not achieve the desired outcome of learning for IE given the overall emphasis on what is learnt and how. Design subjects are better able to address socially oriented skill development and provide context for learning. Contemporary broader design approaches are particularly relevant in addressing cultural competence because of a focus on care ethics, inclusiveness, different values, and power relationships underpinning collaboration.

CONCLUSIONS

For concepts of IE to be effective they should be embedded within a range of units across a curriculum rather than concentrated in a few. This can be achieved with a broader and more integrated curriculum and with a focus on design. A broader approach particularly in relation to design allows for understanding of different ways of approaching a problem thus providing better understanding of interdisciplinary and culturally diverse approaches, as well as differences in what is valued.

KEYWORDS

Integrated engineering, cultural competence, design, professional skills, inclusion

Introduction

A number of papers and statements from a range of sources highlight the increasingly complex nature of society, of the need to be more inclusive, and consequently of the need to educate students more broadly particularly in the area of entrepreneurial and professional skills (for instance, Office of the Chief Scientist, 2013; UNESCO, 2010). These have been accompanied by calls to improve engineering education particularly to improve completion rates, attract diverse students, and better prepare students for engineering practice (Maciejewski, et. al., 2017). In part, and to address apparent deficiencies, engineering curricula included professional skill development in units such as Integrated Engineering. Nonetheless, with emphasis on foundational maths and science concepts and the core disciplinary subjects, there are consequences for the value or status of a more socially oriented unit like Integrated Engineering in engineering curricula, and therefore, to student skill development in this area.

The benefits of Integrated Engineering (IE) are in addressing employers' demands for better communication and interpersonal skills, highlighting to students the expectations of engineering practice, as well as aligning with the generic graduate attributes described by universities. The graduate attributes of Australian universities increasingly reflect wider societal influences and industry requirements becoming more inclusive and aware of the employment landscape with its focus on innovation in driving competitiveness. Consequently, university programs are required to embed, in addition to the usual communication skills, skills such as cultural competence or intercultural communication, innovative thinking and interdisciplinarity.

This paper argues that the aims of Integrated Engineering as a vehicle for professional development are better achieved when embedded in contextualised learning experiences relevant to contemporary engineering practice and when students are given multiple opportunities to practice. This is consistent with current engineering education innovations stipulating a more holistic integrated curriculum overall to ensure relevance and preparation for engineering practice (Maciejewski, et. al., 2017). If engineering is equivalent to design in the sense of addressing problems or presenting solutions using a design methodology, then developing professional skills in an authentic design context that also requires technical knowledge would be a more relevant and engaging learning experience as opposed to separating professional skill development from context. Furthermore, design has the potential to develop broader and inclusive graduate attributes such as cultural competence.

In addressing the question about whether IE is necessary, this paper takes a multipronged approach to identify synergies in briefly reviewing engineering, engineering curriculum, design and cultural competence concepts. Firstly, a background to IE is provided.

Background to Integrated Engineering

Integrated Engineering units were introduced in the 1980s in North America when it was recognised that students required non-technical skills and skills to connect maths and science concepts with engineering practice (Froyd & Ohland, 2005). A study by ABET (2006) revealed that requiring professional skills in the outcomes of HE engineering programs had a positive influence on the work readiness of graduates. Similar outcomes were introduced by other accrediting bodies, such as Engineers Australia. The curriculum of IE varies across institutions. Despite the name, IE is likely to be added-on to an engineering program rather than content and skill development being allocated to a range of units. It is typically not embedded within other areas of the curriculum. There is a perception that IE skills could only be taught in a dedicated unit, separate from other contexts of engineering learning. However, as experts in their field and as role models, teaching staff influence the behaviour and attitudes of students (Danielak, Gupta, & Elby, 2014) to the extent that, for instance, students are likely to follow the communication practices of teaching staff without direct teaching. To better understand IE, it is worthwhile investigating the nature of engineering.

What is engineering?

Engineering is commonly described as design (Elliot, 2010; Lavelle, 2015) which involves a process to create an artefact and the design of the artefact itself (Petersen, Nyce, & Lutzhoft, 2015). It is described as a problem solving activity (Engineers Australia, 2016), as well as a practical endeavour, in contrast to science which is more theoretical or laboratory based (McCarthy, 2010). Less common descriptions of engineering are that it is a ‘social process’ (McCarthy, 2012, p.103) or a ‘social-technical process’ (Lavelle, 2015, p. 268) which means that engineers work with people, machines and environments (Baxter & Sommerville, 2011). Describing engineering as design is contested since, as Davis (2015) argues, it obscures the many other activities of engineers. In contrast, Turnbull, (2010) argues that design is a core activity. Some suggest that engineering is not well understood and/or is understood differently in engineering faculties (Male & King, 2014; Murphy, Chance & Conlon, 2015). Due to the broad nature of activities, engineering is consequently construed as a complex activity (Grimson & Murphy, 2015). For instance, engineering design is complex as engineers need to determine priorities, such as financial, safety, sustainability, performance, and weigh these against values, such as utility, ethics, aesthetics and social considerations (Turnbull, 2010).

HE curriculum

HE engineering programs are described as hard (Winberg, Winberg, Jacobs, Garraway, & Engel-Hills, 2016). Typically, the first and second year units focus on sciences and maths, and engineering theory is taught prior to practice (Male & King, 2014). Male and King (2014) conclude that this makes engineering difficult and less motivating, particularly since learning is not contextualised. This also means the focus is less on the socio-technical aspects of engineering practice, and may therefore appeal more to a narrower range of students (Danielak, Gupta, & Elby, 2014). Furthermore, this may contribute to engineering identities that are inconsistent with engineering practice (Male & King, 2014), and reflect employer dissatisfaction with the interpersonal, communication and leadership skills of graduates (Graduate Career Survey, 2015). HE institutions are encouraged by accrediting bodies to address these aspects of professional development in a program that includes work experience (Engineers Australia, 2008). How these are addressed, whether added on or embedded, is an issue. Mulder (2017) claims that adding on elements to existing programs or units of study (such as, IE) is insufficient. Godfrey and King (2011) doubt this issue considered since there is an expectation that students adapt to faculty culture and programs.

Engineering programs in general consist of independent discipline areas, where maths, for instance may be taught by a different discipline, such as science. The onus is on students to identify how different subject areas connect (Maciejewski, et. al., 2017). On the other hand, an integrated curriculum focuses on creating learning experiences to ensure different disciplinary areas are connected which adds meaning and relevance to the program of study (Fincher, 2016). Fincher (2016) reports that where the curriculum is integrated students tend to better understand and retain subject matter, as well as increase their critical thinking abilities. The curriculum influences learning and engagement. For instance, research has found that females and minority groups are particularly attracted to what is referred to as ‘socially engaged engineering’ (SEE) which covers environmental or humanitarian engineering (Litchfield & Javernick-Will, 2015, p.394). Common elements of these programs are to enhance understanding of contextual constraints, including legal and economic, meet the needs of the local people, and address sustainable use of available tools (Mũnoz & Mitcham, 2012).

Litchfield and Javernick-Will (2015) claim that individuals who are attracted to SEE have “broader interests and motivations than other engineers” (p. 411), and are more open to experiences and driven to do good. However, the findings are that these interests and motivations may be negatively impacted by the curriculum. For instance, a longitudinal study of 326 engineering students at four HE institutions in the US found that students’ social interests declined over the period of their undergraduate program (Cech, 2014). Cech (2014) claims this is due to what is valued in the curriculum. For instance, if students perceived that there was weak emphasis on ethics and social issues, this then correlated with a reduction in social interests. Rulifson and Bielefeldt (2015) report similar findings in their study of 32 engineering students from seven institutions interviewed twice, once at the end of their second semester and then again at the end of their fourth semester. The conclusion is that through the curriculum students are taught to value decisions that preserve the rational scientific aspects of engineering, and consequently, the science and technology aspects are accorded higher values than social, environmental and ethical ones (Cech, 2014). What is valued by a faculty as evidenced in the curriculum influences what students' value.

These findings have implications for initiatives to broaden the appeal of engineering with the goal to improve innovation and thus competitiveness (Office of the Chief Scientist, 2013; OECD, 2015). It complicates the already challenging task of attracting and retaining a more diverse cohort (Eris et al., 2010; Meyers & Marx, 2014). Some of the challenges may be due to conflicting messages about the nature of engineering and who does it. This is evident in the contrast between K-12 engineering programs (i.e. those in school settings) and those in HE (Lachney & Nieusma, 2015). Lachney and Nieusma (2015) argue that K-12 engineering programs embrace inclusive and engaging design-centred activities, while those in HE promote the maths and sciences or 'fundamentals-first pedagogy' (p. 26) in the first years. They also argue that a fundamentals-first pedagogy promotes exclusiveness in preferencing a more limited technical and analytical learning over creative problem solving, with consequences for individuals' personalities, values and emotions in developing an engineering identity.

There is general agreement amongst scholars of SEE that students should be taught systems thinking (Malkki & Paatero, 2012) or more holistic thinking (Lozano, 2010) that incorporates trans- or multi-disciplinary perspectives. This is not confined to SEE. There are calls elsewhere for curricula to implement a holistic framework or ecosystem to better understand complexity and to use systems thinking (Bloom, 2012; Rawlings-Sanaei, 2016). In relation to SEE, the goal is to integrate or embed it within the curriculum (Lozano, 2010; Malkki & Paatero, 2012), rather than adding it on to existing curricula (Mulder, 2017). Mulder (2017) proposes a curriculum that addresses how engineering knowledge could contribute to sustainable development rather than on the foundational elements of engineering or the discipline per se. This kind of objective requires clarity on the role of engineering in today's society and it would encourage a focus on design. The development of systems engineering enabled engineering programs to place more focus on design and less on foundation first pedagogy (Grimson, 2015). A focus on design aligns with project based learning approaches which are interdisciplinary and encourages engagement with context (Grimson, 2015). The principles underpinning systems are similar to those of sustainability as both consider holistic thinking in addressing problems (Elliot & Deasley, 2007). In sum engineering is complex and HE programs influence learning with consequences for what is valued. An integrated curriculum that highlights design and uses systems thinking has the potential to promote a broader approach.

Engineering Design

Design in engineering is generally associated with project-based work (Leigh, Goldfinch, Prpic, Dawes, Kennedy, & McCarthy, 2014), and requires synthesis of core and specialised engineering knowledge (Winberg, Winberg, Jacobs, Garraway, & Engel-Hills, 2016). The outcome of design is generally assessed according to its usefulness and how well it complies with standards and other constraints. However, some believe this is a restrictive approach to design since usefulness might be determined in a narrow way, for instance, from a technical point of view without consideration of a wider social and environment context (Cech, 2014). Determining what the context is (Grimson, 2015) or what is included in a system is challenging or contested (Davis, Challenger, Jayewardene, & Clegg, 2014), since as Cech

(2014) claims, contexts can be designed out of or excluded from the problem concept. This is acknowledged in the literature with calls for a change in thinking to address global challenges (Catalano, 2014; Elliot & Deasley, 2007).

Petersen, Nyce, & Lutzhoft (2015) claim that a restrictive design context inhibits engineers from developing an understanding of human behaviour. Murphy (2016) suggests this is because technology rather than human beings is foregrounded. In recognition of this weakness, engineering design methodology has undergone change since the latter half of the 20th century (Vermaas, 2015). Nonetheless design in engineering is still considered a rational, problem solving exercise with the assumption that by selecting alternative designs, the design problem is solved (Richter & Allert, 2013). The choice selected and evaluation of the design's usefulness is dependent upon the knowledge framework or epistemology of the designer or design team. Thus for instance an engineering solution to a problem would typically involve technology.

One design method that has gained popularity this decade is 'Design Thinking' (Brown, 2009). Design Thinking has broadened the roles and responsibilities around *who* can design placing non-engineers (such as psychologists, or anthropologists) in design roles (Vermaas, 2015). Murphy (2016) proposes that Design Thinking has gained popularity due to techniques to solve complex problems because of its broader sphere of influence and inclusive approach. For instance, "…people, practices, objects, materiality, forms, ideologies, consumption, politics, etc are all afforded attention without having to promote or demote any one of them" (Murphy, 2016, p. 443). In addition, the focus is on the design process and the creative and contextual nature of design (Richter & Allert, 2013). The promotion of this design approach implies that engineering design methods are limited in solving complex problems.

Other inclusive and contextual approaches are evident in range of projects reported in the literature, such as a future car design project which takes into account how a range of people would use the car, including people with disabilities, seniors, children (Kunur et al., 2016). The team working on this project includes engineers, designers, ethnographers. Another project with an inclusive focus is technology for the ageing (Giaccardi, Kuijer & Neven, 2017). Giaccardi, Kuijer & Neven (2017) are critical of technological innovations that produce solutions for single, narrow scenarios based on stereotypes of elderly people. They claim this is due to the problem solving methodological approach of technical design. For instance, instead of seeing ageing as a problem to be solved, another perspective is to see the elderly with different skills and abilities which can be used in creative ways to adapt technologies beyond single use or one function. The orientation to design is more positive. Similarly, Ambole, Swilling, M'Rithaa (2016) argue that design needs to be more than a technological product to address a wider concern with social agency, focus on process, and complex social situations. Rather than a prescriptive design methodology and problem-solving approach, an approach that combines the more descriptive ethnographic framework provides a more holistic concept of the social context. In their case, it was to improve informal sanitation in a settlement in South Africa.

In the cases described, designers and ethnographers collaborate with potential users, who could be considered co-collaborators or participants since they play a role in the design. In these cases, design has broadened to consider consequences rather than just the form of design and the action to produce a design. Consequences arise because design has both direct and indirect impacts on human lives, and therefore has moral implications (Murphy, 2016). Overall this has led to movements that focus on empowerment and sustainability, such as 'Design for Social Change' (Shea, 2012) and 'Design Anthropology' (Otto & Smith, 2013). The wider notion of design with the focus on consequence and empowerment is more compatible with social justice goals articulated in understandings of Cultural Competence (discussed in the following section). As the above examples illustrate, looking at design challenges from different perspectives allows for inclusiveness, but there is also acknowledgement that solutions/products exist within systems and thus less emphasis on one-off product development.

Not all design approaches are equal, for instance, while Design Thinking has been promoted to address innovation in developing countries (Capel, 2014), it has been criticised for promoting or imposing Western design values (Nichols, 2015). Furthermore, critics have linked it to an innovation agenda which is set by global organisations, such as the OECD and World Bank (Capel, 2014; Tunstall, 2013), raising questions about who benefits, and what innovation means for Indigenous and other communities around the world. A recent approach countering this issue is 'Transition Design' (Irwin, Kossoff, & Tonkinwise, 2015). A particularly Australian perspective is 'Indigenous Engineering' (Leigh, Goldfinch, Prpic, Dawes, Kennedy, & McCarthy, 2014) which acknowledges that there are First Australian (Aboriginal and Torres Strait Islanders) and Western worldviews where knowledge is shared and negotiated rather than preference given to one worldview.

Such an approach requires a recognition of different values rather than just Western value systems which Tunstall (2013) argues can undermine the wellbeing of particular groups, as well as their environments. To ensure other value systems can be addressed, broader design approaches propose a design methodology that includes inclusiveness, collaboration, respect for people's values, recognition of politics or power relations and ethics (Capel, 2014; Irwin, Kossoff, & Tonkinwise, 2015). This broader concept of design includes values or axiology. Lincoln and Guba (2000) argue that axiology has been designed out of science to maintain objectivity, leading to claims that science is not concerned with notions of goodness (Goodyear, 2015). Science, and by implication engineering's, reductive approach, simplifies conceptions of the world since what is promoted is a single worldview (Lincoln & Guba, 2000). This then has consequences for what is valued. The higher status of science within Western societies means that its worldview or ideology is dominant thus overriding other worldviews (or value systems) (Lincoln & Guba, 2000). However, solving complex problems requires more than a single worldview and therefore design needs to allow for multiple values and worldviews. It is at this point where the notion of Cultural Competence can be discussed.

Cultural Competence

Incorporating cultural competence (CC) into Australian HE programs was initiated by the Bradley Review (Bradley, Noonan, Nugent, & Scales, 2008), and followed up by reports by Universities Australia (2011a & b). These highlight a history of initiatives to improve the educational outcomes of First Australians, and propose that continuous marginalisation has been a factor in the failure of many of these initiatives. The current situation is that First Australians experience considerable disadvantage in comparison to Later Australians. Disadvantage is, '…any barrier that hinders equity of participation and success in education and labour markets' (Polvere & Lim, 2015. p. 33). CC is designed to improve access to, retention and inclusiveness in, educational programs. The other purpose is to ensure students are aware of the disadvantage experienced by certain groups in society and contribute to improving the social and economic outcomes of these groups thus providing benefit to society generally (Universities Australia, 2011a). Therefore, HE has a significant role in addressing equity and social justice issues. CC is defined by the National Centre for Cultural Competence (2016, para. 3) as:

> *…the ability to participate ethically and effectively in personal and professional intercultural settings. It requires being aware of one's own cultural values and world view and their implications for making respectful, reflective and reasoned choices, including the capacity to imagine and collaborate across cultural boundaries. Cultural competence is, ultimately, about valuing diversity for the richness and creativity it brings to society.*

There has been robust discussion about the definition of culture (Azzopardi & McNeill, 2016; Collins & Arthur, 2010; Wear, Kumagai, Varley, & Zarconi, 2012). One problem with the term 'culture' is the connotation of fixed characteristics of specific ethnic and racial groups;

typically, these are the superficial or explicit characteristics associated with food, dress and behaviours, amongst others (Morris, 2013). This can generate stereotyping and associated assumptions which may form the foundation for racism (Grote, 2008). Dick, et al. (2006) argue that individuals are more than their culture because their behavior, actions and beliefs are influenced by many other characteristics including gender, sexuality, geography, socio-political and economic contexts. Consequently, researchers have suggested other terms such as 'diversity competence' (Chun & Evans, 2016) and 'critical consciousness' (Staub, 2015). The aim is to focus on the complexity of individuals and acceptance of their multiple characteristics rather than on one aspect, such as culture, which can lead to bias and stereotyping.

Dick et al. (2006, para. 30) also suggest recognising the role of power and privilege in understanding the identity of individuals which some argue is at the core of understanding disadvantage (Chun & Evans, 2016). Power could be interpreted as the restriction of choices that one group imposes onto another leading to disadvantage (Nakata, 2007). It is now generally agreed that culture is dynamic rather than static, and involves more than just different ethnicities and races (Azzopardi & McNeill, 2016; Collins & Arthur, 2010; Wear, Kumagai, Varley, & Zarconi, 2012). A similar shift is reflected in current multicultural and cross-cultural literature where culture is now usually interpreted from a critical perspective, such as via understandings of power in society (Chun & Evans, 2016).

From the definition of CC and with a broader understanding of culture, it is possible to identify similar characteristics with broader, holistic design approaches that incorporate values, respect, and ethics. Furthermore, such design approaches are more inclusive and allow for collaboration with individuals and communities as well as acknowledge context, including social, political, economic, cultural elements that individuals and communities involved represent. Given these factors, there is then common ground between CC and design. Here design is *with* rather than *for* which shifts the focus from imposing a design to collaborating in design processes and the learning that entails. Design is acknowledged to shape the future as a consequence of interactions with others and the natural world (Balsamo, 2011; Van Der Velden, 2014), or the way it changes the environment and the ways people interact with it (Love, 2007). Thus, design influences quality of life. Individuals and communities need a say in their quality of life. Incorporating the values of others in design and engineering is therefore important.

IE or design?

While IE curriculum is dependent on the institution or faculty, it is associated with a perception, historically influenced, that it is about professional skills development. Current attempts to modify this perception, whether intentional or otherwise, is with a change in name, for instance, Systems Design (Buskes, 2014) and the use of project based learning. The main problem with some iterations of IE is also a problem of the whole engineering curriculum. Subject matter is segregated and not contextualised. However, learning is contextual. Learning requires language, and that language and the way the information is communicated is done in conjunction with content. It is not possible to separate learning to communicate or work in engineering contexts from engineering itself. As noted in the academic literacy domain, learning, content and communicating are tightly linked (Chanock, 2007; Devereux & Wilson, 2008), and thus that communication skills are best embedded in the context specific disciplinary domain (Arkoudis, 2014). From this position, embedding professional and other skill development within an engineering learning context is a more effective teaching and learning practice. Furthermore, without contextual or authentic experiential learning, skill development tends to be abstract from engineering practice. If that is the case, then students struggle to see its relevance. Another problem is that if there is little emphasis on profession skill development then these are likely to be perceived as having less value or importance particularly when the curriculum emphasizes analytical over creative learning.

Design, particularly, the broad design approaches allow for a range of skill development possibilities. While fundamentals-first pedagogy may take priority in engineering education, evidence shows that early and consistent participation in engineering design results in improved learning outcomes for the professional skills, such as, communication, teamwork, innovative and critical thinking (Kusan, 2014). With a broader design approach, acknowledging additional contextual elements, such as ethics, values, politics, diversity, will contribute to the development of broader professional skills. In addition, broader design is interdisciplinary and together with cultural competence address inclusiveness. A broader context allows for students to develop better understanding in working with a wide range of stakeholders and designing for consequences for these stakeholders. This might involve considering if a technological solution is warranted and examining in collaboration with others what really needs to be achieved acknowledging the social, ethical and environmental dimensions of particular issues.

A broad design approach is likely to appeal to a greater range of students providing diversity in values and ideas, and thus developing the ability to work in diverse groups. Employers are increasingly emphasising the importance of professional skills particularly cultural competence, teamwork, and innovative thinking. Research shows that diversity is beneficial to innovation and thus competitiveness, and that diverse organisations have significantly better financial returns (Deloitte, 2015; McKinsey, 2015). Organisations will therefore try to identify graduates that can contribute to innovation in collaboration with diverse work colleagues.

Conclusion

By articulating understandings of engineering, design approaches and CC, synergies have been identified that provide options in addressing the development of broader professional skills and of the need to be inclusive. Applying knowledge and skills within a context of practice involving design and project-based learning provides experiential learning. Design is a core element of engineering, and it is therefore necessarily integrated. Within a curriculum, design has the potential to resemble modern engineering practice which is interdisciplinary, highly competitive, involves cross-cultural contexts, diverse clients and needs, and requires innovative thinking. However, to be effective a broad design approach should be integrated across the curriculum enabling practice. This would also help ensure that it is valued and has relevance. The answer as to whether IE is necessary is not straightforward primarily due to historical factors about how to teach engineering. These factors may prevent a forward-looking engineering program from meeting the complexity of global challenges and from engineers taking leadership in addressing these. In sum, this paper concludes that a broad design approach is more appropriate as a pedagogical tool than IE.

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