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What unicorns, black swans and red herrings tell us about engineering education futures: A case for futures thinking in curriculum design

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ABSTRACT

CONTEXT

Scientific and technological achievements enabled by computational power and artificial intelligence are rapidly changing our society and the next decade will very likely be different from today. Together with the experience of the pandemic and extreme weather events, preparation for future events and their consequences is essential. Using 'futures thinking', the engineering education community can anticipate and prepare for changes to ensure students have the skills to navigate in an uncertain future.

PURPOSE OR GOAL

A recent report from the Australian Council of Engineering Deans (2021) sets 2035 as a target for achieving a generational change in engineering education. As engineering is multifaceted, anticipating the kinds of problems it will need to address in 2035 provides a blueprint for the design of curricula and the knowledge, skills, dispositions and attitudes needed to address these. This paper explores the value of a futures thinking approach to meet challenges facing engineering education, acknowledging the sustainable development goals, unexpected events, and rapidly changing technologies.

APPROACH OR METHODOLOGY/METHODS

A literature review was conducted on FT, FT in Higher Education (HE) engineering education, and needs of learners to identify the value of developing a futures thinking approach incorporating scenario development for engineering curriculum design and education.

ACTUAL OR ANTICIPATED OUTCOMES

Outcomes of the review are that a broader, participatory and futures thinking approach to curriculum design can produce authentic and realistic curricula scenarios that highlight knowledge and skills development needs for the engineering education community and students. The approach has implications for curriculum planning and approval processes in HE.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The engineering education community, teaching staff and students may benefit from FT to anticipate future possibilities and challenges. There is value in developing FT skills and engineering curriculum design for uncertain futures.

KEYWORDS

Futures thinking, scenario, foresight, curriculum design

Introduction

The Australian Council of Engineering Deans (ACED) 2035 report (2021) indicated the increasing importance of engineering practice to develop the professional skills employers and entrepreneurial ventures (potential unicorns) require. Engaging in entrepreneurial ventures requires being prepared for the unexpected (black swans) as well as unproductive detours (red herrings). 2035 is the year chosen by the ACED (2021) as a generational turning point – students who start school now are likely to be graduating with an HE degree in 2035.Conceptualising engineering education 12-15 years in the future requires thinking about the future, about employment options for students, about the status of engineering and higher education, about the impact of technology and climate change, at a time of great uncertainty. It is because of this uncertainty that exploring possible engineering education futures, even if it is complex, novel and unknown, can broaden understanding and clarify what might be possible (Crews, 2019; Miller, 2018; Rasa, Palmgren, & Laherto, 2022).

Engineering education garners considerable attention given the role governments and industry assign to engineering skills for economic growth, productivity and competition. Regular reports from national engineering associations point to ways curricula can be improved to meet existing and newly determined in-demand skills, such as, emotional intelligence (ACED, 2021). Governments generate initiatives through policies and other actions designed to promote STEM degrees, and to increase STEM graduates, as for instance the Australian 'job ready graduates'. Nonetheless the number of students enrolling or graduating with undergraduate engineering degrees has been declining (EA, 2020; Tayebi, Gómez, Delgado, 2021). While engineering is mentioned as contributing to addressing the Sustainable Development Goals (SDGs) (ACED, 2021), questions arise about the capacity of engineering to integrate these and other social responsibilities (including Breslin & Camacho, 2021).

Other questions arise about the nature of engineering in the future. What can be anticipated based on current signals and drivers of change? What might be different given the focus on the SDGs, climate crises, possible changes to globalisation, government policies and strategies? What likely problems and solutions will engineering need to address, with whom and for who?

The questions highlight the degree of uncertainty and the need to explore approaches that contribute to better preparedness of engineering education and the stakeholders involved. The paper commences with a literature review that outlines what is meant by curriculum before moving onto an overview of futures thinking, engineering futures, engineering education and curriculum, and the future of learning in HE. This is followed by a discussion which synthesizes the findings about the value of FT for engineering education. The final section is a conclusion that highlights key points of the paper.

Literature review

Curriculum

Perspectives about the nature of curriculum differ, and the variety of curriculum models may contribute a lack of clarity (Hicks, 2017). In this paper curriculum design refers to the design of curriculum structures, the sequencing of content over a specific period of time, the goals and learning outcomes, and the design of subjects taught within those structures. It describes the learning experience which is contextualised through alignment with discipline fields, graduate attributes and any accreditation requirements. Curriculum describes assessment and the way in which learning is evaluated. Curriculum is the means through which education occurs (Osberg & Biesta, 2008); education is informed by curriculum, and includes teaching and learning. A curriculum represents knowledge that is valued and the decisions or choices about what is important to learn which may implicitly indicate key disciplinary values and attitudes (Breslin & Camacho, 2021).

Futures thinking

Thinking about the future is described as hard, and individuals typically only think a few years ahead. A survey by Institute for the Future (IFTF, 2017) found that 27% of American adults hardly ever or never thought about their lives five years in the future, and that 36% of them never consider events in their lives 10 years in the future. A lack of foresight or futures thinking is linked to poorer decision making, and a lack of care for the future (IFTF, 2017).

Futures thinking and scenario development are included in the toolkits used by international organisations, governments and policy makers (Kohler, 2021). ‘Futures thinking is a creative and exploratory process that uses divergent thinking, seeking many possible answers and acknowledging uncertainty.’ (Department of the Prime Minister and Cabinet, 2022, para 2). It seeks to develop plausible futures using a range of techniques and data sources, and to take action towards a preferred future. It counters assumptions about the future to generate new insights through enquiry and testing (Department of the Prime Minister and Cabinet, 2022).

Futures thinking is typically used to consider possible futures 10 years from now, and when there is a high degree of uncertainty and complexity (Gürdür, Boman & Torngren, 2021). FT is interdisciplinary and techniques vary across the disciplines with similar and overlapping terms (Kohler, 2021). For instance, other terms for FT include foresight, futures studies, speculative design, design futures. Overall, the objectives are similar in determining possible futures and scenarios as well as actions that can be implemented for preferred options. This review does not provide a critique of the different approaches (see instead Mangnus, Oomen, Vervoort, & Hajer, 2021). It does consider though the value overall of futures thinking for education, in developing curriculum, and for skill development.

There are calls for FT in HE (Gürdür, Boman & Torngren, 2021; Veletsianos, 2020), and more specifically, Salmon (2019) argues for FT for HE curriculum design in the wake of Industry 4.0. Industry 4.0 is used to describe the technological developments enabling automation at large scale with enhanced interconnectivity. The pace of development related to Industry 4.0 has generated employability skills requirements, and thus requirements for HE with a number of papers now mentioning Education 4.0 (Bonfield, Salter, Longmuir, Benson & Adachi, 2020).

In response to calls for FT in HE, Bonfield et al. (2020) present four scenarios representing future education technology trends in HE, and Gürdür, Boman and Torngren (2021) present four scenarios in relation to cyber-physical systems (these systems are associated with Industry 4.0). This paper contributes to this growing uptake.

FT studies have been integrated, most notably, in undergraduate programs at Tamkang University in Taiwan for over forty years (Chen & Hoffman, 2017; Tsang, 2021). Futures oriented PG programs have been running for a similar time in Japan (Tsang, 2021). Examples of recent implementations of FT studies include: secondary science (Rasa, Palmgren, & Laherto, 2022), HE sustainability science (Quinn & Cohen, 2021), and career education (Westacott, 2022).

While FT is described as difficult, studies show that involving students in futures studies helps them develop agency in taking actions towards a preferred future. Tsang’s (2021) findings are that students were more positive about being agents of change for the future. Similar findings are reported in Rasa, Palmgren, and Laherto (2022) who add that the feeling of agency involved students questioning deterministic thinking and assumptions, being more creative in planning, and developing possible solutions to global challenges.

Studies in neuroscience have looked at the role of different FT techniques for motivation and other behavourial change. A recent meta-analysis indicates a strong relationship between a type of FT called Episodic FT, which involves envisioning oneself in a specific, future scenario, with enhanced decision making (Rösch, Stramaccia, & Benoit, 2021). In addition, individuals who imagined a future activity were more likely to complete it (Rhemann, 2018). A positive finding for SD is that associating a feeling when seeing oneself in a future scenario, helps to create a more relatable future; in doing so, individuals care more for the future (Rasa, Palmgren, & Laherto, 2022). The more we are invested in a preferred future, the more likely that we care for that future. This has implications for the SDGs.

Positive outcomes are reported for organisations using FT. Rohrbeck and Kum (2018) present findings on a longitudinal study indicating that organisations adopting a futures orientation were 33% more profitable. To counter some limitations of FT, proponents recommend a wide variety of voices in addressing the question at hand so that scenarios are inclusive, equitable, and focus on collaboration (Goodyear, 2021; Veletsianos, 2020). A greater diversity of views contribute to richer inputs, including generating new insights and overcoming assumptions, in developing scenarios (Crews, 2019). This more inclusive approach aligns with the SDGs. In sum, FT can be useful for anticipating possible education futures as well as for individual skill development.

Engineering futures – what are the possibilities

ACED (2021) argue that the role of engineering is broadening. Samans (2019) claims it is merging increasingly with data science and computing led by Industry 4.0 with its enhanced computing power and connectivity enabling automated manufacturing, AI, and robotics integration into cyber physical systems. In light of recent crises, which have highlighted social justice and climate issues, what will engineering's role be moving forward? Will cyber-physical systems dominate? What other possibilities are there? What will benefit people overall and who will be making those decisions? Certainly, a range of perspectives would help shed light on an uncertain future rather than commit to a deterministic outlook often dominated by artificial intelligence (AI) and technology, sometimes dystopian, as communicated through various media and popular culture.

ARUP (2019), an international engineering consultancy, has developed four possible future scenarios for 2050 to inform decisions for developments in the built environment and for meeting the SDGs. The American Society of Civil Engineering have developed the Future World Vision project which provides resources for future world visioning as part of their mega city 2070 concept. The project includes an immersive environment in which participants experience five city worlds, consider future engineering challenges and outcomes of engineering solutions (van de Lindt, 2022). Other engineering organisations are positioning themselves to address future anticipated challenges relating to climate change, including the Engineering Leadership Group, and the International Coalition for Sustainable Infrastructure.

These are positive directions which may influence perceptions of engineering, and help address skills shortage. However, student interests in an engineering degree have been declining with insufficient numbers of students graduating (NAE, 2008). Initiatives to attract a more diverse cohort including women continue to be challenging (ACED, 2021). Little has changed in relation to perceptions of engineering which found in an RAE (2007) survey that while engineering provides essentials in daily life, it also contributed to climate change. In addition, research confirms a stereotype of engineers, for instance, as masculine associated with construction work (Ergün & Balçın, 2018). Other challenges are around the capacity for engineering to address sustainability which requires social responsibility and related values (including Martin & Polmear, 2021).

If engineering has a role to play in all the SDGs (ACED, 2021), how will this be achieved if insufficient numbers of students graduate? How will organisations adapt? Will students be recruited to earn while they learn? If the role of an engineer broadens, what would this mean for other roles? How much broader is feasible? Should we look at a broader concept of engineering (beyond the engineering discipline silo), and the problems it has to solve? Who will be responsible for solving the problems, and who makes that decision? How will AI impact engineering roles, what impacts do engineering processes and products currently have?

Following the lead of ARUP and American Society of Civil Engineering, it is worthwhile exploring future possibilities for engineering. Indications are that new approaches are needed, including new thinking and methodologies. Dalal (2021) investigated the value of four different ways of thinking: futures, values, systems, strategic, for addressing engineering challenges. For futures thinking, the results '…suggest the need for long-term, imaginative thinking that informs current education…' (p.139). Dalal's findings together with that of the previous section suggest that engaging in FT as a process is beneficial for individual skill development as well as for the outputs, such as future scenarios, from which decisions can be made.

Engineering education and curriculum

There is a growing demand for improved teaching and learning practice to enable students to tackle uncertainty, unexpected events and a broader range of skills than that of ten years ago. ACED (2021) anticipate that for 2035 a "future oriented" engineering program would include development of entrepreneurial skills and professional practice skills involving "big picture thinking", "emotional intelligence" and "interpersonal skills", as well as strong relationships between industry and the community.

Entrepreneurial education leads to a range of beneficial student outcomes, for instance, there is a positive relationship between entrepreneurial education and resilience (Hartmann, Backmann, Newman, Brykman & Pidduck, 2022). Resiliency can be developed along with futures thinking through education (Egan, O'Hara, Cook, & Mantzios, 2021). Resilience is relevant for its role in dealing with the unexpected; and it is seemingly key to entrepreneurial processes with further research required (Hartmann, et al., 2022). As resilience is relevant in dealing with unexpected and challenging or overwhelming situations, it is useful for situations, such as those represented in entrepreneurial and venture capital contexts described as 'black swans', 'unicorns' and 'red herrings', as well as for health and climate crises.

Another benefit of entrepreneurial education is the development of student agency as students are encouraged to act (Jones, Penaluna, & Penaluna, 2019) as well as to endure failure and start over (Hartmann, et al., 2022). Agency is connected to FT because 'agency involves the idea of projection and implies anticipation' (Cuzzocrea & Mandich, 2016, p. 553). Agency goes beyond current concepts of knowledge and skillsets for employability. The title of Edgar and Edgar's (2020) paper "students should prepare for life, not just work", sums up this concept of agency. Goodyear (2021) argues that agency is not a passive condition that entails doing what others want, but it is about being "agents of collaborative change". The impetus for agentive change sits well in the realm of FT, and not just entrepreneurial education, given the goal to consider how a preferred future could be actioned.

Shaping a preferred future, one that is valued and beneficial for the self and others is, according to Goodyear (2021), a design activity. For curriculum, this requires curriculum designers to consider how to '…design to expand the capabilities of people to lead the kinds of lives they value' (Manzini 2015), or create the conditions that enable this. An FT approach to curriculum design would be to collaborate with others to design possible future scenarios, and a collaborative design effort would contribute '…to quality enhancement and curriculum transformation.' Kelder and Carr (2016, p.197). It is envisaged that students, as "agents of collaborative change" would be a key stakeholder contributing to the design of their future. This challenges a division between students and teachers reflected through terminology, such as learning and teaching, and the classic Biggs' statement 'what the teacher does, what the student does'. Hicks (2017) proposes eliminating the division so that we say "what we do together".

While curriculum is influenced by external organisations, the HE institution and by the discipline, it is itself influential. It can, for instance, influence retention and motivation through the sequencing of subjects/units and the nature of the content. Male and King (2014) claim that the focus in first year engineering programs on theory and rote learning associated with maths and science subjects means that learning is not contextualised, and is thus, more difficult and less motivating. The lack of context or decontextualisation in the engineering curriculum is a source of concern for a more values oriented education (see, for instance, Breslin & Camacho, 2021).

To improve enrolments and retention, some engineering programs have introduced innovative curriculum, including Olin College of Engineering as reported in Graham (2018). However, a curriculum is more than the knowledge and skills expressed in learning outcomes and measured through assessments. It also reflects the values and attitudes of a discipline. Findings of a study involving engineering students at four HE institutions in the US were that their social interests (e.g. humanitarian engineering, sustainability, professional and ethical responsibilities) declined over the period of their undergraduate program (Cech, 2014). Cech (2014) concludes this is because of what is valued in the curriculum. For instance, if students perceived that ethics and social issues were less important, this was associated with a reduction in social interests. More recent studies confirm that learning ethical skills does not occur even in project based learning contexts (Picard, Hardebolle, Tormey & Schiffmann, 2022), and that teaching staff prioritise technical skills consistent with engineering culture (Martin & Polmear, 2021).

The conclusion is that a curriculum can influence values, and that this occurs in engineering education in prioritising technical knowledge (Breslin & Camacho, 2021, p. 53). This raises questions over current initiatives in addressing sustainable development (SD) within a conventional curriculum given that efforts to include more socially oriented values have been challenging (Breslin & Camacho, 2021 and references therein). Advocates for SD in engineering argue that a futures orientation is needed to achieve SD as part of a new set of "competences" (Beagon, et al., 2022) or skills.

It is also recognised that SD education is not an 'add on' to existing curricula but a new approach (Kolmos, Hadgraft, & Holgaard, 2016). Mulder (2017) suggests a focus on systems rather than the technical, as well as, on future studies to allow students to make links to societal challenges; and Romero et.al. (2020) proposes a transformative and holistic approach. Skills for SD have been identified as part of a Spanish engineering education project (Albareda-Tiana, et al., 2020) from which learning outcomes were developed, and then mapped to the SDGs proposed by UNESCO. The learning outcomes cover contextualising knowledge to predict impacts, applying ethical principles of sustainability for interventions that contribute to the common good, and promoting activities in communities.

The identification of SD skills (Albareda-Tiana, et al., 2020; Beagon, et al., 2022) have enabled the development of learning outcomes for curriculum. This and other work indicate progress to incorporate values and socio-technical elements into the curriculum. For instance, a number of studies show the benefit of problem and project based learning combined with context for improved learning and a range of social and professional skills (Guerra & Rodriguez-Mesa, 2021). Joslyn and Hynes (2022) propose Transformative Learning pedagogies to develop sociotechnical understanding to counter a rationalist, dominant engineering mindset and to encourage openmindedness in the social aspects of engineering. Work is also occurring to improve K-12 STEM and engineering curriculum in the US where there's a move from inquiry-based science learning to design-based learning (Huffman, Strimel, Parry, Zarske, & Turner, 2021). The research and outcomes of K-12 engineering education could contribute to enhancing engineering education into a coherent program of study across schools and HE.

FT involves a range of practices including developing scenarios. Like entrepreneurial learning, FT also builds agency and resilience while enabling a broader perspective of the context for education in the future, and care for that future. FT requires skill development of all stakeholders, not just students. Chen and Hoffman (2017) report on the benefits of FT studies for teaching staff at Tamkang University which include anticipation of new technologies and ongoing changes impacting the university, and using FT to improve learning. Thus, teaching FT builds capabilities as well as those of the learners.

Future of learning in HE

HE is complex with multiple stakeholders, many moving parts, interactions and their consequences (Parsons & Shelton, 2019). There are competing interests, and competition to address flexible learning, as well as students with varying motivations including career advancement or career maintenance (Ruthotto, et al., 2021). The rapid transformation to online learning due to COVID-19 led to intense interest in the delivery of learning with questions around the futuring of the university. Bozkurt (2022) argues that HE will need "resilience, adaptability and sustainability skills" to survive.

Facer (2022) proposes that universities need "rigorous and reflexive imagination" going beyond understanding the current situation and aspirations for a desirable future to explore a future of possible radical disruption. This exploration can highlight where there are gaps in knowledge, blind and blank spots. It is possible that reports like those of the ACED haven't fully considered the impact on HE and associated professions from unexpected climate, economic, civil or other possible disruptions. FT can contribute to new ideas, and thus overcome organisational mindsets, assumptions and narrow thinking about possible futures (Crews, 2019). FT allows for exploration of the unknown and the uncertain with more diverse participants. FT would help identify and encourage action on preferred, authentic future scenarios, and in the meantime participants engaging in FT develop futures literacy, which, as Miller (2018) claims, is an essential 21st century skill.

HE institutions (HEI) are likely to welcome information to avoid being surprised, unprepared or being led in an unproductive direction. The pandemic was a surprise for many, and some in HE were somewhat prepared because of existing initiatives to provide online learning. An example of an unproductive direction for some HEIs were MOOCs. Early last decade they were touted as being a major player, and a number of universities invested resources in them only to find low student retention (Riel & Lawless, 2018). Now the investment is in the postgraduate space, most notably with the launch of 'MicroMasters' (exclusive to EdX) programs. These have grown in popularity especially since some HEIs, like Rochester Institute of Technology, will accept any MicroMasters certificate toward their masters degree (Moore, 2022). This is a signal of change which appears to be strengthening; it aligns with new directions in finance with distributed, rather than the traditional centralised, ledgers. Instead of the centralisation of learning, that is learning confined to a single institution, it is possible that learning becomes more decentralised or distributed. Indeed this is suggested by the IFTF (2021).

Discussion

Previous sections discussed the ways in which a curriculum can be influential on motivations and values. It was noted that engineering skills are in demand, but there are difficulties recruiting and retaining students. A trend in HE is the alignment of Industry 4.0 with an emerging concept of Education 4.0. Industry 4.0 with its cyber-physical systems is not well understood. Developing possible future scenarios would contribute to a better understanding.

The use of FT for engineering curriculum design and/or education appears to be limited, while FT studies are well established in HE curriculum in some countries. Learning, and/or participating in, FT is associated with numerous benefits for participants, stakeholders and organisations, such as, abilities for navigating uncertainties, complexities and unexpected events. One beneficial ability that is developed is agency allowing participants and, most importantly, students to shape their lives.

Engineering is expected to address the SDGs, but current curriculum in the main is not well aligned to address the non-technical elements inherent in these. However, examples of revised curriculum to incorporate social responsibility and values associated with the SDGs are emerging which may encourage adoption across the HE sector. Other curricula changes, such as, integrating cyber-physical systems may be motivated by industry and/or government with new and changing job roles. It is recognised that changing curricula is often resisted, but FT offers a novel approach that can develop a sense of care for the future, and is therefore worth exploring.

An FT approach to curriculum encourages a broader participation and diverse views through its potential to be interdisciplinary and inclusive. Allowing for diverse participation can generate new insights, avoid assumptions and set ideas. It may counter what is seemingly inevitable, thus avoiding what *has to be* based on the past and current context. Participants in an FT process become invested in creating authentic and preferred scenarios; and visualisations of, and action for, the future can be more concrete.

Conclusion

The future is anticipated to be complex and potentially disruptive. In this context, FT offers a structured, proactive approach to identifying possible futures and preparing for a preferred future. FT would add value to engineering education and curriculum in at least two ways; firstly, to identify plausible engineering education futures and new insights through a broader, collaborative and diverse approach allowing for clarity about, for instance, the influence of the SDGs, or technology on learning and job roles; secondly, to develop capabilities to shape a preferred future. Overall, future thinkers would be better prepared for unseen events (black swans) and to recognise false leads (red herrings) so as to support successful ventures (unicorns).

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