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Using Artificial Intelligence to Humanise Engineering Education

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ABSTRACT

CONTEXT

The work of professional engineers significantly impacts society and the environment. Beyond the scientific and technical concepts taught in engineering programs, there is a growing interest in ensuring that graduates can understand and manage the societal implications of their profession. However, embedding these aspects into engineering education has proven challenging and remains a concern. The emergence of Artificial Intelligence (AI) for teaching and learning offers new perspectives and potential solutions to address these challenges.

PURPOSE OR GOAL

This study explores how the impact of AI in engineering education, in terms of curriculum content, cognitive processes, and pedagogical methods, creates an opportunity to promote a more human-centered approach to engineering education.

APPROACH OR METHODOLOGY/METHODS

The article revisits the recent evolution of engineering education and conducts a scoping review of the use of AI in this field. The former sets a direction, and the latter reveals a greater potential. On that basis, we follow a futures research approach, conducting an extrapolative analysis to depict a plausible future and identify areas where AI can facilitate greater socio-technical balance in the engineering curriculum.

ACTUAL OR ANTICIPATED OUTCOMES

The outcome of this study is a provocation for engineering educators to reflect on the use of AI in education beyond its application to the already existing contents. The findings support the use of AI to enhance the engineering programs in often-overlooked aspects of the profession, such as ethics, social responsibility, and the ability to envision a sustainable future.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Based on AI generative conversational agents' potential to realise teaching and learning efficiencies, we conclude that they provide an opportunity to free up space in the dense technocentric curriculum and to accommodate greater emphasis on socio-environmental awareness, including sustainability and circular design. We also conclude that the inclusion of these aspects in the engineering curriculum is needed more than ever before given the potential for AI to accelerate and augment the engineering activity and its social and environmental impact.

KEYWORDS

Artificial Intelligence, AI, socio-technical engineering, sustainable engineering, human and social aspects of engineering, human-centered engineering.

Introduction

The engineering activity transforms the world around us and the way we live, playing a crucial role in the achievement of most of the 2030 Agenda for the United Nations Sustainable Development Goals (SDGs) (UN General Assembly, 2015). The impact of the engineering profession in society and the environment has been documented for decades (Greber, 1966), although recent studies still show that it is often not fully reflected in engineering education (Lantada, 2020; Lee et al., 2022).

As the fifth industrial revolution unfolds, attention is shifting globally towards human-centred sustainable growth, which places a steady interest in the social aspects of the engineering profession. A range of initiatives are seeking to review engineering curricula to deliver the graduates that industry demands in this context. In Australia, the Council of Engineering Deans (ACED) conducted a major review of professional engineering, the Engineering 2035 project, and made recommendations to equip graduates with the necessary knowledge, skills, and attributes for the new work environment. The findings are consistent with previous ACED's reports (King, 2008) and with international trends, implying that the professional engineering curriculum needs to increase the exposure to engineering practice, enhance the core engineering ways of thinking, and reinforce the human and social context where engineering takes place, highlighting the need for integration of human and social dimensions within the technical contexts (Lee et al., 2022).

The interest in balancing technical and socio-environmental aspects in engineering education is not new (DeJong-Okamato et al., 2005), but it has proven challenging, and the technical-social dualism in engineering education continues being a matter of concern (Rodrigues and Cicek, 2024). The technical content dominates engineering education, academics set a technocentric culture and the delivery of the curriculum lacks exposure to sociotechnical discussions, making students develop a view that engineering is a purely technical profession and that other skills are not relevant (Niles et al., 2019). Although academics appreciate the importance of the socio-environmental context, they find it challenging to fit it in the dense technical content that takes up the curriculum. A range of approaches have been proposed, with limited success, mainly looking at intertwining short sociotechnical elements across subjects throughout the curriculum or providing standalone elective subjects. A key impediment for greater balance is the reluctancy to compromise technical content.

In parallel, generative conversational agents, have emerged as a tool with potential to disrupt teaching and learning. Generative Pre-trained Transformer (GPT) applications, such as ChatGPT, are Artificial Intelligence (AI) based natural language processing systems that provide responses to queries, from simple questions to more elaborated conversations. Their use and misuse have been a topic of intense discussion in recent times, mainly around the threat they pose to academic integrity. The present study takes a different stance, picturing a more positive possible future; on the one hand, we look at GPTs' potential to facilitate cognitive off-loading and realise efficiencies to free up space in the engineering curriculum. On the other hand, we outline AI's potential to augment and accelerate engineering projects. We then discuss the nature of the engineering activity and reflect on where it is heading if its pace and footprint increase, underscoring the social and environmental responsibilities, and their greater relevance in this context.

Methodology

The use of AI in engineering education is still in early stages; being a general tool, AI allows developing a wide range of applications that can shape different scenarios and use cases. Given the uncertainty in what the future use of AI may hold and the determining role of engineers in influencing that future, we choose a futures study methodology based on an explorative forecast (Puglisi, 2001). As an explorative study, we look at the future from the present, in contrast to normative methods that investigate what needs to occur to achieve a specific goal. We depict a plausible future by looking at present trends and exploring where they might lead us.

We briefly revisit the recent evolution of engineering education, which shows a direction, then we conduct a scoping review of the use of AI in engineering education and in the workplace, which shows the potential. Together they set the foundation for an extrapolative discussion where we describe how AI underscores the imperative for a human centred and sustainable discourse in engineering, and at the same time provides the means for greater socio-technical integration in the curriculum.

Social Trend in Engineering Education

Changes in engineering programs are primarily driven by new scientific and technical advances in the profession, as well as the need to acquire essential skills to adapt to the evolving practices in the field. The evolution of engineering education is often linked to the industrial revolutions, the first one characterised by the steam engine and mechanisation; followed by the introduction of electric power and chemical processes in the second one; digitalisation with electronics and automation in the third one; and today's cyber-physical integration, IoT, AI and advanced materials in the so-called Industry 4.0 (Vieira, 2024). While still amid this forth industrial revolution, the concepts of Society 5.0 and Industry 5.0 are starting to emerge, seeking a future balance between economic progress and the resolution of social problems, which has motivated the discussion around Engineering Education 5.0, a term first coined by Lantada (2020).

Although engineering practice has always been associated with improving human's well-being, it has only been at the beginning of the 2000's that humanitarian engineering started as a discipline, aiming at addressing inequalities in access to engineering solutions, especially in developing countries, and advocating for a shift in the education paradigm, moving away from a transactional model with a hierarchical relationship between teacher and student, towards learning by posing problems and discussing solutions that integrate technical and non-technical aspects, framed by an attitude of community service (Baaoum, 2018). Humanitarian engineering has been progressively expanding from minors to majors and whole engineering programs, as a standalone discipline rather than as an intrinsic element of engineering practice.

Historically, across engineering disciplines, the curriculum has been characterised by its strong emphasis on scientific and technical content, with additional subjects often considered complementary. Engineering breakthroughs during World War II triggered the evolution of engineering education from a technical practical focus to placing emphasis in science and mathematics; and afterwards it shifted to outcomes-based education, steered by professional accreditations (Froyd et al. 2012). In the 20th century, engineering design was strengthened, and some programs began to incorporate additional subjects into their curricula as a consequence of the industrial contexts in which engineers worked. These additional subjects typically included business, regulations, production, sustainability, and economic fundamentals, with emerging interest in transversal skills such as communication, teamwork, collaboration, critical thinking, and professionalism, including ethical and societal aspects.

Aligned with this trend, there is an expectation that the training of future engineers prepares them to be active contributors to the achievement of the SDGs (Romero et al., 2020), and accrediting bodies are reviewing the expected competencies and student outcomes for greater emphasis on sustainable development and consideration of impact, with statements on graduates' abilities such as "ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts." (ABET, 2021) or "Identify, formulate, research literature and analyse complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences with holistic considerations for sustainable development" (International Engineering Alliance, 2021).

The development of these competencies has been implemented in different ways depending on the universities (Gumaelius and Kolmos, 2019), trying to address the challenges posed by several constraints, such as limited time, academics' preference for technical content, lack of expertise in these topics, especially in technical universities, and governance processes around integrating new subjects. Given the continuous and accumulated innovation and transformation, these challenges are growing, and we are reaching a point where, as expressed by Gürdür Broo et al., (2022), "one just cannot teach it all" (page 3) and relevant knowledge may reach the limit of what we can absorb. Furthermore, recognising the diverse backgrounds with which students enter the engineering programs, there is a keen interest in student-centred and personalised learning, which, especially after the pandemic, is expected to be scalable and accessible remotely.

Use of Artificial Intelligence in Engineering Education

AI has been developing for decades and has progressively found its way into popular debates around automation, recommendation systems, customer profiling, smart marketing, and self-driven cars, among others. It has broadened its reach further as applications of large language models and generative artificial intelligence (GAI) have become mainstream, following the introduction of ChatGPT in late 2022, which shook the foundations of academic integrity with its capacity to generate credible products of learning (Bearman et al., 2024). Having overcome the initial fears and attempts to curtail its use, GAI is currently seen as an opportunity to innovate in teaching and learning, with potential use in personalised tutoring, automated feedback, language translation, and interactive learning (Baidoo-Anu and Owusu, 2023).

The idea of supporting teaching and learning with virtual teachers is not new, with interventions based on teacher-bots and cloud-lecturers explored since the introduction of technology in educational settings. Remarkably, early on, the research in this field showed that the most fruitful approach sits in the coexistence and mutual reinforcement between teachers, students, and machines, away from a dualistic (human, machine) debate (Bayne, 2015). More recently, Al Husaeni et al. (2024) conducted a review of the use of smart chatbots as educational tools in science and engineering education and highlighted their use to better develop students' 21st century skills. Empirical evidence is starting to emerge in broader implementations where learning flows are redesigned to make use of AI and empower students and lecturers (Pham et al., 2023).

In relation to students' use of GAI, Lodge et al. (2023) proposed a typology of uses based on human-computer interaction in education research, which considers the cognitive and social processes involved in learning and builds on the potential to reduce cognitive load and free up mental space. Cognitive offloading refers to the reduction of the mental processing required to undertake a task by using an external tool (Risko & Gilbert, 2016). It has been the object of research mainly in Human Computer Interaction literature, exploring how supportive technology reduces the mental demand and allows using the intellect elsewhere or enables engagement in higher order cognitive tasks. The use of GAI in education is being considered in two broad ways, one is as a support in the learning process that is withdrawn as the learning occurs, and the other is as a support allowed only after the achievement of the intended learning outcomes is demonstrated.

In engineering education in particular, the way in which AI is transforming the workplace is being analysed to update content at subject level and, holistically, to lift the program learning outcomes for graduate employability (Tucker et al., 2020). Beyond particular content necessary to conceive, design, implement and operate AI supported systems, engineering programs are looking at ways of familiarising students with AI as a productivity tool, able to remarkably augment work throughput (Wilkens 2020). Human augmentation is not new either, the interest in enhancing abilities and cognition have been a constant in history, and engineers' role has been instrumental, with endless examples of tools and technologies developed to that effect; in doing so we have introduced complexity around us and at the same time a means to deal with it (Johri, 2020). Engineering educators are progressively incorporating in their teaching the range of AI-based resources available to enhance engineering practice.

However, the most significant impact of AI in engineering education is the potential it has to transform the teaching and learning processes, supporting a more personalised experience, enhancing learning, and helping with assessment and curricular planning (Martín Núñez and Diaz Lantada, 2020). Rathore et al. (2021) reflects on the importance of personalisation in learning and how it has been a shortcoming in current educational systems that can be addressed by using AI to create a more customised learning experience. In relation to impact on assessment, Nikolic et al. (2023) have conducted a multidisciplinary and multi-institutional benchmarking of ChatGPT to ascertain its potential to compromise integrity in engineering education. The availability of ChatGPT is forcing to change the focus from merely assessing the outcome or artifact to observing the learning process itself, aiming for a more effective and authentic assessment of graduates' competencies and attributes (Cao & Dede, 2023). In relation to curriculum design, Jauregui-Correa and Sen (2024) provide insight into a much broader transformation linked to AI’s role in knowledge retrieval and dissemination, questioning the current structure based on the division of required knowledge into a fixed set of subjects, with a given duration, over a set period of time, and delivered by a designated academic often at a particular location, while content is pervasive and available almost everywhere.

Adoption of AI in Engineering Practice

AI is undoubtedly transforming the processing and the outcomes of engineering activities. It is affecting the way engineering systems are conceived, designed and managed, and new ways of incorporating AI in the workflow continue to emerge in every field of engineering with abundant survey studies available in the literature over time, such as Stephanopoulos (1990) or the recent one by Nurullah et al. (2023). The detail on how it is being used goes beyond the scope of this study. However, the overarching aspect is that the adoption of AI in the workplace is augmenting and accelerating work.

A key aspect is understanding what "augmentation" means in a specific field or profession. The primary interpretation of this term is the ability to do more, or increased efficiency—essentially, the ability to do things quicker. In science, augmentation often relates to the ability and speed of achieving new discoveries, increasing knowledge, or improving our understanding of the world. In engineering, this concept can be similarly understood as the ability to create new systems, apply knowledge in innovative ways or solve problems more effectively and efficiently. Engineering tasks often include designing new artifacts and equipment that transform the world and interact directly with people. Interestingly, engineers tend to overlook this aspect of their profession associating their activities primarily with problem-solving tasks (Jonassen, 2014). While problem-solving is undoubtedly a crucial part of their work, this narrow view can limit the perceived scope and impact of their contributions. Through problem-solving, designing, and their various professional endeavours, engineers inevitably create significant alterations in their surrounding environments. They influence the context in which they work, affect the natural environment, shape communities, alter human interactions, change work processes, and impact on social inequalities, among many other aspects.

Therefore, augmentation is of particular relevance to engineering because of the transformative impact that engineering projects have in societies and the environment, and because it is mainly through engineering systems that AI finds its way into the world (Johri, 2020). That sets apart engineering from other disciplines in the way in which AI is to be embedded in practice and in the curriculum. Furthermore, AI has the potential to facilitate the integration of increasingly complex engineering systems, supporting a 'system of systems' approach (McMillan and Varga, 2022). In this context, the socio-environmental responsibility has greater relevance and justifies a renewed need to understand and manage the impact of engineering practice, which further underscores the importance of including these aspects in engineering education.

In summary, the amplification of engineering activities, including increased productivity, complexity and impact, is intrinsically linked to greater responsibility. Environmental considerations, the role of the circular economy, and social controversies surrounding engineering activities become central to the engineering profession. Historically, technological advances have delivered increased efficiencies that have translated in greater productivity and impact on the social and natural environment. AI tools have the potential to exacerbate this trend at a faster pace, justifying a renewed consideration about the limits of growth (Vincent and Brandellero, 2023).

Discussion and Practical Implications for Engineering Education

The use of AI in engineering education and practice is nascent and not yet representative of its full potential. AI is a versatile technology with various applications, some already in use and many yet to be developed. If trained adequately, GAI conversational agents can facilitate access to and acquisition of knowledge in an unprecedented personalised and ubiquitous manner. Tools like ChatGPT have proven to be helpful in filtering, aggregating and synthesising internet content in a way similar to how humans communicate. Their performance, however, is as good as the content used to train them. As humans, we tend to anthropomorphize ChatGPT capabilities and forget that all it does is to extract statistical patterns from the large volumes of content currently available on the internet. In the Data, Information, Knowledge, Wisdom (DIKW) pyramid, widely used in information systems and knowledge management, GAI is still in the first stage (Peters et al., 2024). This is because AI conversational agents arrange available content structuring it into information, but they fall short of understanding the deeper meaning that constructs knowledge and develops wisdom. These higher order abilities require insight into ethical principles, human values, and societal contexts. Therefore, GAI conversational agents may become a valuable support or an alternative to traditional lectures, facilitating the transmission of content, which can spare academics from repetitive tasks, but not replace them, at least any time soon. Academics can play a key role in customising conversational agents with validated discipline-specific content to support a more personalised learning journey.

These teaching and learning efficiencies enable cognitive off-loading for students and academic staff. In this scenario, GAI conversational agents may trigger a shift from ‘digestion of knowledge’ to greater application of knowledge, where ‘doing’ becomes more important than ‘knowing’. For this to occur, students will need enhanced querying and critical thinking skills in order to be able to find relevant and purposeful information. In relation to academics, with generative conversational tools facilitating content anytime anywhere, it is necessary to reflect on the purpose of attending face-to-face classes and think of a more human-centric use of contact hours. For both students and academics, consideration should be given to the use of the capacity freed-up by the cognitive off-loading. The trend in engineering education and practice discussed above supports using the teaching and learning efficiencies to introduce higher order cognition, which involves a range of sophisticated thinking skills related to critical reasoning, decision making and problem solving.

Still, in considering the cognitive offloading, the question remains about what constitutes essential knowledge and competency aspects that graduates must demonstrate without support. This requires a shift in the academic discourse from ways of teaching (pedagogy) towards what to teach (learn) and what to assess. The assessment cannot be based on artifacts that can be produced by generative AI tools, instead it has been recommended to shift towards assessment of the learning process (Lodge et al., 2023b). However, recognising the variety of backgrounds of current students’ cohorts and the interest in broadening access at different stages in life, the learning process may differ significantly from one student to another. Therefore, we argue that rather than trying to find ways to assess the learning process, the focus should shift towards the observation of achievement of the expected competencies. This is consistent with output based professional accreditations, such as that of Engineers Australia (EA), which is not focused on the process as long as the course of study leads to graduates able to demonstrate achievement of the competencies expected for entry into the profession (e.g. EA Stage 1 competencies).

The observation of attainment of competencies may be complex and too onerous to be implemented with the same frequency that assessment is currently conducted, with multiple assessment items in each subject or unit of study. Furthermore, it may be challenging to effectively assess competencies independently, especially the human and social ones, which are often intertwined with the technical ones (Radu et al., 2024). In this context, programmatic assessment is of renewed interest to improve decision making about the achievement of the program-level learning outcomes (Govaerts et al., 2022). With the focus on intended competencies, the number of assessment points can be reduced throughout the program of study. Although the concept is straightforward, the implementation has proven challenging with the main concern being the integration of longitudinal assessment pieces and academics' additional workload. These can be revisited as AI tools unfold their potential to support academics in answering student questions, providing supplementary explanations, and personalised feedback on academic progress (Hwang et al., 2020).

The literature review shows that most of the studies on AI for engineering education are still conceptualisations with theoretical base. Time will allow for more empirical research. Nevertheless, AI has brought to the fore the need for a holistic review of engineering education. It is forcing a review of teaching and learning practices, including content, pedagogy and assessment. At the same time, it is providing the tools to rationalise the curriculum, assist with scaffolding of knowledge, focus on higher levels of cognition and create the space to enhance humanistic approaches. By envisioning this possible future, we hope to assist academics identify where some of the opportunities to influence the development of AI tools lie.

The considerations above are closely related to the role of engineers in society. Are engineers being educated mainly to perform technocratic tasks? Can we envision engineering graduates with greater agency to shape the future beyond the technical specifications of engineering designs? The integration of AI into educational programs offers new and innovative alternatives to advance this transformation. Based on GAI conversational agents' potential to offload and realise learning efficiencies, embedding them in teaching and learning provides an opportunity to free up space in the dense technocentric curriculum to accommodate greater emphasis on ethics, responsible decision-making, socio-environmental awareness, including sustainability and the importance of circular design. The inclusion of these aspects in the engineering curriculum is needed more than ever before given the potential for AI to accelerate and augment the engineering activity, and its social and environmental impact.

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