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Three Frameworks to Support Engineering Education to Develop with Generative AI

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ABSTRACT

CONTEXT

Generative AI (GAI) challenges our education system in general, and engineering education is no exception. While the initial focus has been on academic integrity, there are many opportunities for this technology to enhance student learning. Balancing the challenges and opportunities is difficult for academics without a clear understanding of how GAI affects learning.

PURPOSE OR GOAL

With the article, we want to inform study boards and lecturers' adoption of GAI and adaptation of the engineering education programs to the new reality. Our intention is to ensure that this renewal of the programs also includes a discussion of what we train engineers for (solving complex problems), what role GAI and the students play in the study practices, as well as how the competencies are assessed when GAI can dilute the difference between the able and the less able student.

APPROACH OR METHODOLOGY/METHODS

The article is a position paper that argues for an approach to the phenomenon of GAI in engineering education. The article presents and discusses three frameworks derived from research-based perspectives related to recent development of engineering education.

ACTUAL OR ANTICIPATED OUTCOMES

The article does not offer ready-made conclusions that readers can implement in their own practice. The article instead offers concepts with which to think about the development of engineering education.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The article recommends that study boards and lecturers in engineering education consider: 1) What types of problems their engineering students are asked to tackle, as well as the progression in these types of problems; 2) How engineering students are taught and supported to use GAI to augment rather than replace their thinking; 3) Rethinking assessment of competences, so that it is human judgment and reasoning that is rewarded rather than the use of GAI.

KEYWORDS

Generative AI, Problem Types, Assessment Design

Introduction

Across the 20th century Australia saw significant decreases in the proportion of employment in the agricultural and mining sectors, while manufacturing grew and then shrank again, with changes partly due to improvements in technology and automation (Connolly & Lewis, 2010). Knowledge work, however, has long resisted the pressures of automation. Australian Higher education remains a largely labour intensive sector, with more than half of university expenses going to salaries, and academic staff numbers growing by nearly a third from 2008 to 2019 (Universities Australia 2022).

The recent advances in Generative Artificial Intelligence (GAI), exemplified by the launch of ChatGPT in late 2022 (OpenAI, 2022), have presented significant disruptions to traditional modes of engineering education, and particularly traditional text-based modes of educational practices (Wang, 2023). Historically the only way for universities to operate was manually with people; now we have other options. Artificial intelligence has been described as a technology that has the capacity to automate our knowledge work, and in many cases to do so without degrading the quality of our teaching. Educational researchers have highlighted visionary ideas of how AI and GAI technologies can transform educational practices, for instance through enabling personalized tutoring and tailored lesson plans (and thus, individualisation of education), reducing teaching workload, and supporting student-teacher interaction (Wang, 2023; Baber et al., 2023; Perera & Lankathilake, 2023). However, limitations and threats to teaching and learning practices have also been widely reported in contemporary scholarly literature. For instance, the risk of overreliance and diminution of learning, mechanical teaching, reduction of human-human interaction, amongst others (Miao & Holmes, 2023; Wang, 2023; Williamson, 2023).

In order to explore these opportunities, however, we must first be able to conceptualise the impact that this technology will have on our curriculum and embrace it as an opportunity to develop engineering education that fits the 21st century. In this article, we present three frameworks that might be useful as thinking tools for proactively developing engineering education with GAI and not just reactively adapting the curriculum to avoid cheating. This paper presents three frameworks that are useful to frame engineering education of the future with regards to:

- Problem types: The Cynefin framework
- Technology Usage: Augmentation vs replacement
- Robust assessment: The defibrillator problem

By exploring each of these frameworks, this paper will provide mental models to assist engineering educators in engaging with GAI technology in their classrooms.

Problem Types: The Cynefin Framework

Consideration of the types of problems to which GAI is applied types gives substantial insight into why GAI is so effective in some cases but so problematic in others. The Cynefin framework (Snowden & Boone, 2007) provides a way of considering different types of problems (Figure 1). The Cynefin framework distinguishes problems based upon their level of complexity, and on the types of approaches that are consequently required to respond to such problems.

Simple problems are such that they can be categorised; they are familiar, there are best practice solutions, and thus it is a matter of recognising them and applying the correct solution. Complicated problems require analysis before they can be addressed, but the information required for that analysis is already available. Complex problems require probing to find the necessary information, with interactions between different sub-parts of the problem, and will require solutions to emerge along with the information. Chaotic problems are such that action is required in parallel with the problem – it cannot wait while a solution is generated, and novel strategies are required.

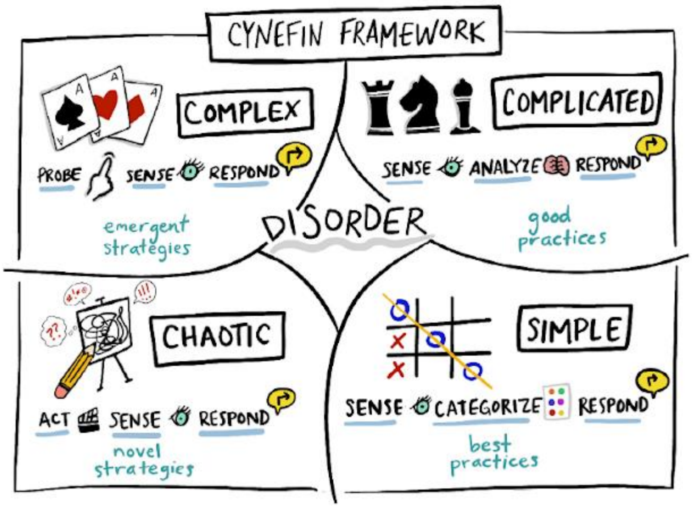

Figure 1: The Cynefin Framework (Bytepawn, 2024)

Engineering education has long had a dissonance between how we teach and what we expect of our graduates. We aim to prepare engineers who can work in the complex and chaotic quadrants, dealing with the wicked problems that the real world provides. We aim to achieve this, however, by focussing upon the complicated and simple quadrants of technical analysis in our curricula.

There are legitimate historical (and pedagogical) reasons for this focus: engineers cannot work in the complex quadrant if they cannot decompose the problem down to complicated and simple parts; engineers need to be able to operate to standards, and should value the predictability of applying best practice solutions; and teaching and assessing in the complex and chaotic quadrants is a challenging and expensive proposition.

The drawback of a curriculum focussed on the complicated and the simple quadrants is that these are the quadrants for which there are good practice and best practice solutions, and thus there are myriad examples available for use in training GAI systems. As a result, we see that GAI systems are remarkable in their performance in tasks for which there are good exemplars, such as passing the bar exam for lawyers (Weiss, 2023).

Conversely, we also see that GAI tools struggle when they are asked to address tasks that require emergent or novel strategies, such as the development of new synthesis of information, particularly when references are involved. It is often in these kinds of tasks that we see “confabulations” or “hallucinations” from GAI systems, where a plausible but nonetheless false example is given by the system.

While not conceptualised in this way, these distinctions are to some extent borne out by Nikolic et al’s (2023) investigation into the use of ChatGPT and assessment, with ChatGPT performing best in areas where there are good training exemplars, and struggling most where specific contextual judgement is required.

It is perhaps useful to note that there is some overlap in the explanatory power of the Cynefin framework and Bloom’s taxonomy (Anderson, 2001). There is strong alignment between the lower levels of Bloom’s and the simple quadrant, and it is difficult to engage with chaotic quadrant problems without using the higher levels of blooms taxonomy. It is possible, however, for chatbots to perform well on higher order thinking where they have been trained with multiple exemplars, or to perform poorly at the lower levels of Bloom’s taxonomy if they have not been trained with the relevant facts. For this reason, we propose that the Cynefin framework better scaffolds an insight into the performance of GAI.

Technology Usag: Augmentation vs Replacement

Over the past year, it has become apparent that GAI and AI technologies offer multifaceted applications in teaching and learning processes; operating with humans, alongside humans, or operated by humans to offload work. Therefore, a key consideration is the nature of use and type of relationship between the machine and the human teacher and learner.

Several scholars have proposed frameworks for making sense of these complex and multifaceted relationships. Notably, Inge Molenaar (2023) introduces two perspectives on the integration of GAI in teaching and learning to frame our thinking about GAI in education: the 'replacement perspective' which historically envisioned AI systems like Intelligent Tutors taking over teacher tasks, and the 'augmentation perspective' highlighting AI's role in supporting human teachers and learners, enhancing rather than replacing human intelligence.

Similarly, Lodge et al. (2023) present a typology of potential student–GAI relationships, distinguishing between 'cognitive offloading' - using tools and technologies to delegate basic cognitive functions and free up mental capacity for other tasks – and 'extended mind' – using tools and technologies a type of prosthesis, extending and enhancing the human mind into the world, functioning as part of our cognitive processes.

It was fear of the replacement and offloading of learning that drove the initial flush of effort (and publications) in GAI towards academic integrity issues. The ability of students to use GAI to replace their learning through the generation of assignments on (mostly complicated / simple quadrant) tasks meant that academics were no longer able to adequately distinguish what was human and what was GAI generated. As such, the conversation among educators, practitioners, policy makers, and perhaps also the general public alike was marked by a predominant focus on the end product of learning, rather than on the process of learning itself.

Using GAI to offload the production of an end product (e.g., an assignment) is naturally of significant concern. However, a hyperfocus on this type of interaction may obscure us from grasping and developing other types of interactions that support learning, drawing upon the augmentation and extended mind perspectives. An early effort to contribute to a nuanced conversation about multifaceted learner–GAI interactions was presented by Mollick & Mollick (2023), who identified seven roles that GAI could play to support student learning, while keeping the teacher and learner in the loop of control and regulation:

1. *AI as mentor* providing feedback to connect gaps between current abilities and intended learning outcomes
2. *AI as tutor* providing direct instruction and pushing students to think through problems, connect ideas, and offer feedback and practice
3. *AI as coach* increasing metacognition and helping students articulate their thoughts and reflect about past and future events
4. *AI as teammate* increasing collaborative intelligence and helping teams articulating and thinking through problems
5. *AI as student* helping students check their understanding and fluency about a topic
6. *AI as simulator* creating opportunities for practicing skills in new situations
7. *AI as tool* extending the amount of work students can do

The majority of Mollick & Mollick's (2023) roles (1-6) actually represent augmentation approaches rather than replacement approaches (7).

Robust Assessment: The Defibrillator Problem

A specific consequence of the Augmentation vs Replacement issue is the inability to distinguish technology enabled novices from those who have achieved proficiency – the "Defibrillator Problem". A defibrillator allows for a bystander with no training or experience to resuscitate a person – they are able to rely upon the technology to substitute for proficiency. GAI tools have shown a similar effect in helping novices work at a proficient level. It is who are the least capable that benefit the most from GAI support tools, while more expert users show little gain, or in some instances a degradation of performance (Mollick, 2024).

In the operating context of a defibrillator, it is only the outcome that is important. But in the context of assessment, where we are using the outcome as a way of measuring competence, there is a vast difference between technology enabled novices and proficient students. Historically, the only way to operate at a proficient level was to become proficient, which meant that we could use summative assessments of proficiency as a way of measuring learning. GAI tools are breaking this link, challenging the robustness of our assessment.

The inability to identify technology-assisted proficiency will change the ways in which we use different types of assessment. For formative assessment, the risks are lower. Students who cheat on formative assessments are ultimately only cheating themselves out of a learning opportunity. For summative assessments, however, the risk is higher, because these are the tools we use to verify competency in our quality assurance systems. It is likely that many assessment tools that have heretofore been used summatively will only be viable as formative assessment in the future.

Discussion

Each of these frameworks shares a commonality that they require us to be purposeful in our use of GAI. What kinds of problems do we want our students to explore? How do we want them to use GAI tools? And most importantly, what do we want them to learn as they do so?

Historically the only way to perform at a proficient level was to become proficient, and becoming proficient was an intermediate goal on the path to mastery. GAI tools are breaking down this pathway, presenting us with key questions to consider as we design our curricula. Is proficiency itself the goal for our students? Or is it an intermediate milestone?

If the goal is merely proficiency, should we be developing proficiency, or supporting the use of the technology to emulate proficiency? Engineers Australia's accreditation standards (Engineers Australia, 2019) make a distinction between professional engineers, engineering technologists, and engineering associates. Professional engineers are expected to handle unfamiliar problems in unfamiliar contexts, which requires more than just proficiency. But as our curricula become increasingly crowded we must ask ourselves whether they require expertise across all of our curriculum, or whether proficiency is an adequate endpoint in some instances.

Engineering education has dealt with technology transitions before. The use of a slide rule was once a core skill for all engineers; now new technologies automate our calculations, providing significant new capabilities. This is the crux of the GAI challenge – it augments the capabilities of capable practitioners while simultaneously offering novices a pathway to avoid ever becoming proficient.

As educators, GAI allows us to shift the focus of our education away from the repetition of well-worn best practice exercises towards the creative and evaluative thinking that is essential for good engineers. In doing so, however, it is critical that both teachers and learners are aware of the consequences of transitioning to these tools. The use of these tools itself becomes a proficiency, and one that cannot be outsourced by the students. Uncritical use of these tools risks novices practicing outside of their expertise, and being unaware that they are doing so. It is essential that the use of these tools is accompanied by an understanding of their function, and of the limitations of their capabilities. Critical use of these tools, however, provides significant opportunities for students to explore new types of problems, and to augment their learning to enable them to focus on their mastery.

The Cynefin framework also affords the opportunity for a meta-insight in our own approach to tackling the introduction of GAI in education: At this point in time, teaching with GAI is a chaotic quadrant problem. There are no best practice answers, novel strategies are being developed, and we must act on the problem while we attempt to solve it. This is in stark contrast to much of the traditional model of teaching, where we have quite stable (if outdated) best practice approaches to how to teach. Many of our academic colleagues are seeking the certainty of a simple quadrant approach to a technological revolution that is yet to leave the chaotic quadrant.

Conclusion

The recent arrival of artificial intelligence tools have allowed both students and academics to automate tasks that previously had to be completed manually; and in doing so they have challenged some of the key assumptions of the engineering education paradigm.

Considering artificial intelligence as an automation technology, and considering what it can automate, and how it goes about that automation is an essential step in coming to terms for what it means for each of us in our teaching.

Providing frameworks to conceptualise GAI is a valuable contribution to assist academics in understanding the roles that GAI can play in their teaching. By considering the types of tasks for which GAI is (and is not suited), the ways in which students will use GAI tools, and the kinds of outcomes and assessment that we want from GAI-supported learning, we are better able to incorporate artificial intelligence in our curriculum.

Many previous technologies, such as calculators and Google have been incorporated into engineering curricula after initially being resisted. These frameworks are intended as a lens to assist in the adoption of GAI technologies in a responsible, thoughtful way that can enhance the learning of our students.

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