Using the TPACK Framework for Gen-AI Enabled Learning Activities: Design, Delivery and Evaluation

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***Abstract*— This paper explores the integration of Generative Artificial Intelligence (GenAI) tools in engineering education through the Technological Pedagogical Content Knowledge (TPACK) framework. By designing and implementing AI-enabled learning activities, the study demonstrates how GenAI can enhance student engagement, critical thinking, and overall learning outcomes in the modern classroom. The research was conducted in the context of a two-week intensive course on engineering solutions for a sustainable world, where activities such as AI chatbot discussions, AI-based image generation and AI-designed quizzes were employed. Student feedback on all activities indicated high levels of engagement and improved understanding. The findings suggest that AI tools can make learning more interactive and enjoyable, streamline teaching and assessment processes, while allowing the educator to foster critical thinking and reflective abilities in students. Recommendations for broader implementation center around considerate design of AI-enabled learning activities that align with learning outcomes and requiring students to critically evaluate AI-generated outputs. Thereby, this work serves as a case study for integrating AI in a pedagogically sound manner, offering valuable insights for educators aiming to leverage AI to enhance the student learning experience.**

***Keywords*—Generative Artificial Intelligence; Learning activities; Student engagement; TPACK framework.**

***ICTIEE* Track*:* Pedagogy of Teaching and Learning**
***ICTIEE* Sub-Track: Pedagogy for the Modern Classroom-Strategies for Engaging Students through AI**

I. INTRODUCTION

The integration of artificial intelligence (AI) into education represents a significant opportunity to enhance teaching and learning, similar to the introduction of digital tools in previous decades. Broadly speaking, 'technology-enhanced learning' has been identified to address four different objectives: (i) as a support tool for face-to-face learning, (ii) as a learning tool to acquire specific expertise, (iii) as an enabler of remote or distance education and (iv) to deliver inclusive education (Daniela, 2021). Despite the widespread proliferation of digital tools in higher education, and specifically in engineering education (Hrynevych et al., 2021; Szłapka et al., 2020; Udugama et al., 2023), meta-analyses have revealed the best use of technology to be 'as a supplement to normal teaching rather than as a replacement' (Higgins et al., 2012). Unlocking new ways for communication and collaboration, immersive learning environments, interactive problem-solving and gamification are some of the prominent features of technology-enhanced learning (Kirkwood & Price, 2014; Taylor et al., 2021).

The TPACK framework, developed by (Koehler & Mishra, 2009), offers a comprehensive model for understanding the integration of technology (TK), pedagogy (PK), and content knowledge (CK) in teaching. It emphasizes that effective technology integration requires an understanding of the complex relationships between the three components (Benson & Ward, 2013; Koehler et al., 2013). The framework is an effective way to ensure that technology is not being integrated for technology's sake; instead, content knowledge (the subject matter) and pedagogy knowledge (methods of teaching and learning) form the foundation for any effective educational technology integration. Similarly, today's educators must navigate the complexities of AI integration, and drawing parallels to the TPACK framework can help address this in a pedagogically robust manner. Professional competence in digital tools was a challenge for educators (Hughes, 2005) and likewise, challenges around ethical considerations, data privacy concerns, and the need for professional development dominates the current landscape with respect to the use of AI in higher education (Holmes et al., 2022). However, if these challenges are addressed, appropriate integration of AI and digital tools can unlock significant benefits for the student learning experience, such as enhancing active learning (Barbetta, 2023; Tautz et al., 2021; Wang, 2020), critical thinking (Haghparast et al., 2014; Meirbekov et al., 2022) and metacognitive abilities (Azevedo & Aleven, 2013; Drigas et al., 2023). This 'appropriate integration' would require 'an understanding of how teaching and learning can change when particular technologies are used in particular ways', which (Koehler & Mishra, 2009) define as the intersection of TK and PK, equivalently referred to as technological pedagogical

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knowledge (TPK).

AI technologies have been employed in multiple facets of engineering education, including personalized learning where AI tools have made it easier to tailor educational content to individual student needs and monitor student progress (Chassignol et al., 2018; Lu et al., 2018). Over the more recent past, access to generative AI (GenAI) technology has further widened the horizon in engineering education albeit with challenges around ethical issues as stated earlier (Qadir, 2023). Educators have also found the use of GenAI tools to generate lesson plans to be efficient (Karpouzis et al., 2024). Furthermore, as with other disciplines, tools like ChatGPT have ramifications for assessment methods used in engineering education with issues around academic integrity (Al Braiki et al., 2020; Nikolic et al., 2023).

Despite these challenges, the access to GenAI tools present an opportunity to improve student engagement. The principle of constructive alignment emphasizes aligning learning activities to learning objectives and assessment tasks (Biggs & Tang, 2010). Based on constructivist learning theory, students construct understanding through experiences and reflection offered by learning activities, and in the case of AI-enabled activities, constructive alignment will ensure that AI tools are purposefully leveraged to meet specific learning outcomes. The conversational framework proposed by (Laurillard, 2013) is a robust model for designing learning activities that promote engagement and deeper understanding. As per this framework, learning activities can be classified into six types: acquisition, inquiry, discussion, practice, collaboration, and production (Laurillard, 2013). Each of these types vary in degree of student passivity and hands-on experience: learning through ‘acquisition’ is the most passive of these as the learner is not required to do anything explicitly. Learning through ‘inquiry’ and ‘discussion’ are more active learning approaches as they require students to compare, critique and analyse resources and arguments. Learning through ‘practice’, ‘collaboration’, and ‘production’ often unlock pathways to hands-on experiential learning. Duly considering these diverse types of learning activities in the context of the TPACK framework would constitute a pedagogically grounded approach for the design and delivery of AI-enabled activities to engage students during classroom teaching (Pamuk, 2012). This is vital since the domains identified in the TPACK framework are often intertwined and not easy separable (Archambault & Barnett, 2010).

This article documents how the TPACK framework and classification of learning activities can be used to design and deliver AI-enabled activities for a course on engineering solutions for a sustainable world. Thereby, strategies to engage students through AI are developed with a solid grounding in pedagogical principles. The article then proceeds to analyse student feedback on engagement and how the activities were beneficial to the student learning experience. Besides tracking high-level student satisfaction, the analysis reveals the specific ways in which students perceive their understanding of engineering concepts to have improved by these AI-enabled activities. Thereby, this article holistically addresses the design, delivery and evaluation of GenAI-enabled learning activities, which engineering educators can easily translate and adapt in their teaching practice.

II. Course context and design of learning activities

Strategies to engage students through AI were explored in the context of a two-week intensive international summer course offered at a xx University. The course was attended by 24 students, who were mostly undergraduate students from a variety of engineering backgrounds (chemical, civil, environmental, electrical). The course covered the following topics: (i) Sustainability challenges and engineering principles, (ii) Engineering technologies for carbon capture, utilisation and storage, (iii) Life cycle assessment (LCA) for environmental sustainability, (iv) Energy transition, (v) Sustainable food systems and (vi) Role of engineering in healthcare and pandemics. In terms of the TPACK framework, the specific components that constituted content knowledge (CK) are captured in Fig. 1.

As stated in the introduction, the knowledge of teaching and learning (PK) that was used to inform the design of learning activities was: principle of constructive alignment (Biggs & Tang, 2010), types of learning activities (Laurillard, 2013), flipped classes (Karabulut-Ilgu et al., 2018) and emergent skills of active learning, critical thinking, metacognition and reflection (Fig. 1). In the context of this work, technological knowledge (TK) refers to digital literacy, and more specifically, the use of GenAI tools. Although GenAI can produce content in several different forms, the TK for this study were restricted to text and image outputs (Fig. 1). The four AI-enabled activities developed using the TPACK framework are described below.

A. Activity 1: Discussion with an AI chatbot on sustainable development.

At the start of the course, students are introduced to terms like sustainability, sustainable development and climate change (CK). Exposure to these definitions are typically instructor-led, which constitutes learning by ‘acquisition’ (Laurillard, 2013). To improve student engagement with these terms, a learning through ‘discussion’ activity was designed (PK). Since the term ‘sustainable development’ has been critiqued by some as being an oxymoron and paradoxical (Redclift, 2005), students were first asked to think and decide whether they agreed or disagreed with the position. They were then engaged in a ‘discussion’ activity with a GenAI chatbot (ChatGPT). The chatbot was asked to give a detailed argument on the opposite position to what the students had agreed on. This was followed by an in-class discussion between the students and instructor on the GenAI output.

This activity was designed with an intention for students to see the arguments of the other side and assess these arguments for their merit. Alongside engaging students in critical thinking and analysis, an added benefit of this activity was for students to appreciate the limitations of the GenAI tool (TK), in terms of identifying when arguments were reasonable and related to the topic of interest and when the GenAI tool was ‘hallucinating’.

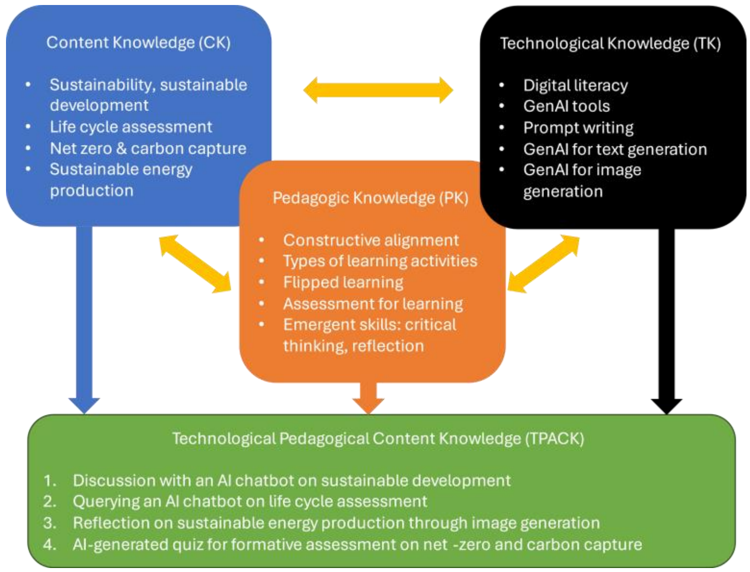

Fig. 1. Design of Gen-AI enabled learning activities using the TPACK framework.

B. Activity 2: Querying an AI chatbot on life cycle assessment.

After fundamentals of life cycle assessment was taught to students, they were assigned a research paper on comparative life cycle analysis of toothpaste cream and toothpaste tablets (CK) (Suppipat et al., 2022) to read as homework. As a follow-up on the next day in class, this exercise served as the basis for a learning by 'inquiry' activity (Laurillard, 2013) in a flipped class environment (PK). With students having engaged with the paper before class, the activity was designed to surface the scenarios being considered for LCA, the methodology followed, and the main findings presented in the paper. The ability of GenAI tools to process and analyse large amount of text to create new content was leveraged for this activity (TK). Students were asked to upload a pdf of the research paper to Microsoft Copilot and query the following:

(i) What are the two scenarios being considered for the LCA?

(ii) What is the methodology/approach being followed for LCA?

(iii) Based on the LCA results, how do the (a) environmental and (b) health impacts of using toothpaste tablets compare to using toothpaste cream?

(iv) Based on the LCA results, what recommendations would you make for manufacturers of (a) toothpaste tablets and (b) toothpaste cream?

The series of questions was designed to go from closed questions (answers directly provided in the text) to more open-ended questions (answers would need interpretation of provided data and text). Based on their own understanding of having read the paper, students were then asked to critique the responses provided by Microsoft Copilot. Although GenAI tools can be used to summarise documents, this activity inculcates a more investigation-driven approach to student learning and engagement (Laurillard, 2013), looking at critiquing the credibility of responses to specific questions as opposed to a general overarching summary.

C. Activity 3: Reflection on sustainable energy production through image generation.

The course included a one-day field trip to a biomass power station. This field trip was designed to promote experiential learning after concepts of sustainable energy production and energy transition had been delivered in class (CK). It was vital that students couple their learnings from the field trip to the underpinning fundamentals taught in class; this requires students to engage in reflection and metacognition. Reflective exercises can be undertaken through a series of individual journaling prompts. However, this activity was designed to promote learning through 'production' and 'collaboration' (PK).

Hence, on the day after the field trip, students first had to individually reflect on their key takeaways from the field trip. Subsequently, they had to share their reflections in small groups and use Microsoft Copilot to generate an image summarizing their key takeaways (TK). The collaborative 'production' of such an image draws on similar production-based approaches reported in the literature for reflective thinking, such as production of web folios (Turky, 2016). Each group then posted their generated image with a brief description on an online post-it board (Padlet) to enable discussion with the instructor and the rest of their peers.

D. Activity 4: AI-generated quiz for formative assessment on net-zero and carbon capture.

To ensure that students are following concepts being taught on the course, 'assessment for learning' was an integral consideration of course design (PK). This is also typically the opportunity for the instructor to identify any common misconceptions and address these in subsequent teaching. A short formative test based on multiple choice and fill-in-the-blank-type questions was offered at the mid-point of the course. The test was designed to assess student familiarity to basic concepts like net-zero, carbon and ecological footprint, types of carbon capture technology and renewable energy production and storage (CK).

Although the use of such formative tests is widespread, in this case, the questions for the quiz were generated by an AI tool built into the University's virtual learning environment (VLE). The AI-based design assistant incorporated into the VLE reviewed the lecture material (uploaded as pdf files by the instructor) on the course page to generate a series of questions, which the instructor then reviewed and approved to be used in the formative quiz (TK). Since the test was offered online, student responses were automatically marked and the right answers to all questions were visible to students immediately thereafter. Hence, this activity significantly reduced the workload of the instructor in terms of assessment design as well as marking.

III. EVALUATION METHODOLOGY

Student feedback was collected at the end of each learning activity – except the formative test – through a brief anonymous questionnaire on the 'JISC Online Surveys' platform. All students enrolled on the course were eligible to complete these snap surveys but participation was voluntary. The questionnaire was designed to collect student opinion on (i) how engaging and enjoyable the activity was, (ii) use of critical thinking during the activity and (iii) if and how their understanding of the topic was improved through the activity. Questions investigating (i) and (ii) were framed on a four-point Likert scale, while for (iii), respondents were asked to describe how the activity improved their understanding.

The quantitative data from the Likert-scale questions are processed and presented in the subsequent section. The qualitative data from the free-text question was coded by the author to identify different themes. Principles of inductive thematic analysis were used for this purpose and no pre-conceived ideas or frameworks were used to develop themes on how leveraging AI in the activity potentially helps student understanding. Finally, student performance data from the online formative test was analysed to evaluate overall class performance and identify any specific concepts/questions that students found challenging.

IV. STUDENT FEEDBACK AND ATTAINMENT

Student feedback for all three activities is positive (Table 1). While the discussion activity on sustainable development received the highest percentage of favourable responses for being enjoyable and engaging (91% either agreed or strongly agreed; Table 1), the image generation activity received the highest percentage of 'strongly agree' responses for the same statement. Among the three activities, it is only the third that engages students in 'production' and with students potentially not having been exposed to GenAI for creating images previously, the relative newness of such GenAI usage is expected to have contributed to making the activity more enjoyable. This is reflected in the following student quotes:

TABLE I
STUDENT FEEDBACK ON GEN-AI ENABLED LEARNING ACTIVITIES.

Statement	% Strongly Agree	% Agree	% Dis-agree	% Strongly disagree
Activity 1: Discussion AI chatbot on sustainable development (n=23)				
The activity was enjoyable and engaging	30	61	9	0
I engaged in critical thinking during the activity	43	48	9	0
Activity 2: Querying an AI chatbot on life cycle assessment (n=24)				
The activity was enjoyable and engaging	42	42	16	0
I engaged in critical thinking during the activity	33	63	0	4
Activity 3: Reflection through image generation (n=21)				
The activity was enjoyable and engaging	67	23	0	10
I engaged in critical thinking during the activity	48	29	13	10

'I have no experience with creating images on AI, and it was cool to see how it could take our takeaways and create an image shockingly similar to what (we) saw'

'The image generated from the AI is good. And it's amazing because it's the first time I use it.'

Students also agree to engaging in critical thinking during these activities. An overwhelming 96% either agreed or strongly agreed to this statement for Activity 2 (Table 1). As explained previously, this activity was designed to query a series of questions in increasing complexity, starting from well-defined closed questions and proceeding to open-ended subjective-type questions. Consequently, students were required to critically evaluate the AI-generated responses based on their understanding and interpretation of the research findings presented in the paper. During the flipped class discussion, students opined that the GenAI tool (Microsoft Copilot) produced an accurate response to the question regarding the methodology/approach of the LCA, adding that it did include further information on sensitivity analysis that was not required. For the question on the recommendation to toothpaste cream and tablet manufacturers, students opined that the generated response was less accurate with some important aspects based on the presented results being overlooked. While the response was not wrong entirely, students felt that the question surfaced the limitations of the GenAI tool. This conversation eventually helped the instructor to close the loop by going back to the research paper to discuss the recommendations based on the data presented therein.

Similarly, the discussion points generated by the GenAI tool (ChatGPT) in Activity 1 required students to evaluate the merit of each point put forth. While students commented that some of the points in the generated response were valid and that students themselves did not consider these before, they also suggested that the response included several tangential points that were not fully relevant to the discussion. Hence, critical thinking was a core element of the activity, duly reflected in the 91% of favourable student responses for the corresponding statement (Activity 1, Table 1).

When asked a binary question on whether the activity helped improve their understanding of the topic, a large majority of the

Fig. 2. Percentage of student respondents who stated that the activity helped improved their understanding of the topic.

student respondents answered in the affirmative for all three activities (Fig. 2). As a follow-up, these students were asked to describe how the activity improved their understanding. For Activity 1, the overarching theme of student comments was exposure to aspects of sustainable development that they hadn't thought of prior to engaging with the AI tool:

'Give me some new directions to think.'

'I got more ideas of sustainability from an opposite perspective, like consumption, ecological footprints and so on.'

By bringing together these different viewpoints, the activity enabled students to gain a more holistic and rounded perspective of sustainable development. As for Activity 2, improvement in student understanding mostly centred on comparing their answers to the AI-generated responses. This was facilitated by the capability of the AI tool to summarise information, albeit with some limitations:

'Compare the answers of Gen AI with my understanding of the paper. I can review my understanding and see how Gen AI works.'

'By using AI chatbot, it sometimes made wrong answers, but it was easy to use and had a good performance. So, easily to summarize and understand the contents.'

With respect to Activity 3, reflective ability was a common theme in a number of student comments. Although this is most likely because of the instructor's reference to this skill when introducing the activity, it is reassuring to see students stating that the activity indeed helped them meaningfully reflect on the field trip. Thereby, leveraging the TPACK framework for GenAI activity design is successful in promoting students' reflective ability on sustainability in addition to technical competence. Furthermore, several students referred to this being their first ever experience of using an AI tool to generate images. Overall, the novelty in using GenAI tools for in-class learning activities resulted in broadening horizons, and was a common undercurrent in the student comments received across all activities:

'I am not super familiar with AI, and i was shocked by how comprehensive and helpful it can be. I appreciate that it can help generate ideas, but also recognize where it might have its limits.' (Activity 1)

'As someone who has little experience with AI but recognizes that it will become a part of education in the future, this type of activity is perfect. I am able to learn how to responsibly use AI. I can see where it can be helpful and effective, as well as where it has its limitations. I like to see it used as a tool for education, rather than something evil. And I like to see it being recognized as something with faults, rather than something you can fully trust.' (Activity 2)

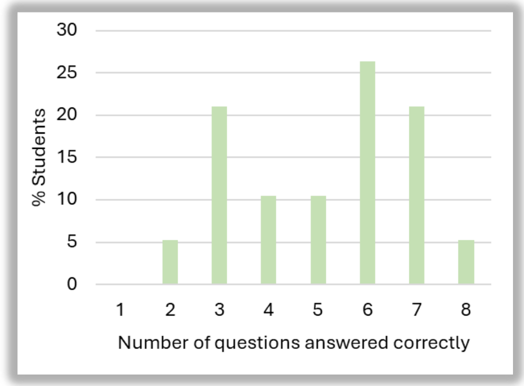

Fig. 3. Student performance in the AI-generated formative test (Activity 4).

'I practiced how to generate AI images by entering proper prompts and upgrade with the more process.' (Activity 3)

On student attainment, Fig. 3 shows the distribution of student marks in the formative test (Activity 4), which comprised 8 questions in total. 19 students attempted the formative test and close to 65% of them answered at least 5 questions correctly. Offering this test through the AI-enabled VLE allowed the instructor to see the mark distribution and question analysis immediately after closing the test. For example, more than half the students were found to have answered the question 'What is the term used to describe the balance between the amount of greenhouse gas (GHG) that's produced and the amount that's removed from the atmosphere?' incorrectly. While the answer to the question is 'net-zero', a few students had chosen 'carbon neutral' as their response. This allowed the instructor to immediately emphasise the difference between the two terms. Thereby, the AI-enabled formative test offered the following advantages: (i) autogenerated questions with minimal instructor effort (ii) automated marking and (iii) opportunity for the instructor to immediately address misconceptions based on AI-generated question analysis.

CONCLUSIONS

This study demonstrated the effective integration of GenAI tools within the framework of Technological Pedagogical Content Knowledge (TPACK) to enhance student engagement and learning in engineering education. As demonstrated with a range of learning activities, GenAI can be a powerful ally in driving learning goals when used thoughtfully and purposefully. Thereby, the use of the TPACK framework ensures that AI integration is pedagogically sound and content-relevant. Through such considerate design of learning activities, AI was leveraged to foster critical thinking, reflection, and active learning among students. The positive student feedback and improved understanding of engineering and sustainability concepts underscore the potential of AI to transform traditional teaching methods.

The findings from this study have two main implications for the wider engineering education space. Firstly, the use of

GenAI tools, such as chatbots and image generators, can significantly increase student engagement by making learning activities more interactive and enjoyable, as evident in the high percentage of favourable survey responses to all activities piloted in this study. This is particularly important in engineering education, where concepts can often be challenging to grasp, and students should do more than just be passive recipients of new knowledge or information. Secondly, AI-enabled activities that require students to critique AI-generated content or reflect on their learning experiences, as was demonstrated in this study, can enhance critical thinking and metacognitive skills. These skills are crucial for engineering students who must navigate complex problem-solving scenarios in their professional careers.

Although this paper demonstrated the advantages of GenAI-enabled learning activities in a standalone course, going forward, more rigorous studies examining the long-term effects of AI-enabled learning, for example, through longitudinal studies, will help formulate a better understanding of this emerging topic. In conclusion, the integration of GenAI tools in engineering education, guided by existing pedagogical frameworks, such as TPACK, offers a promising pathway to improve student engagement, critical thinking, and overall learning outcomes. By adopting these strategies, educators can create a more dynamic and effective learning environment that enhances the student learning experience as well as student attainment.

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