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A Framework for Understanding the Role of Generative AI in Engineering Education: A Literature Review

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Abstract

This complete research paper conducts a comprehensive literature review to explore the role of Generative AI (GenAI) tools in undergraduate engineering education. The rapid development and widespread adoption of large language models (LLMs) and GenAI tools have introduced both opportunities and challenges in educational environments. While previous tools like spellcheckers and grammar checkers have been commonly used, the advanced capabilities of GenAI models necessitate a re-evaluation of their integration into the learning environment. This study aims to address the fragmented understanding of GenAI's impact by mapping out emerging themes from current literature, thereby developing a cohesive framework that highlights key issues, opportunities, and challenges.

The literature review encompasses academic databases, focusing on search terms such as "GenAI," "ChatGPT," and "Generative AI in engineering education." Relevant papers are analyzed to identify common themes, which are then synthesized to provide a thematic overview of GenAI's role in engineering education. Initial findings suggest themes around ethical considerations, pedagogical shifts, and the potential of GenAI to enhance student learning. Ethical concerns, such as algorithmic bias, privacy, and academic integrity, are highlighted, alongside the need for continuous upskilling of both students and educators.

This study aims to offer a comprehensive understanding of GenAI's implications in engineering education, serving as a valuable resource for educators, institutions, and policymakers. By identifying and synthesizing recurring themes, this framework will guide future research and policy development, ensuring the responsible and effective integration of GenAI tools in engineering education.

Introduction

Since the introduction of generative pre-trained transformers and other generative artificial intelligence (GenAI) tools, the use of GenAI tools has grown significantly. While Artificial Intelligence (AI) has been around for decades, GenAI has emerged more recently. The launch of OpenAI's generative pre-trained transformer model—more widely known as GPT— made these tools widely accessible to almost anyone [1]. As a result, people across different fields have found a range of uses for these tools, including in engineering education [2], [3]. Despite the widespread use of GenAI tools, they are still relatively new in engineering education. This introduces uncertainties, including issues regarding ethics, accessibility, and algorithmic bias [2], [4]. There are also concerns around the lag between the rapidly growing uses of GenAI tools and the current policies regarding their uses in engineering education [5], [6].

In addition to ChatGPT, there have been other GenAI and large language model (LLMs) based tools, with widespread uses for students, educators, and researchers in engineering education [2], [3]. This has created opportunities for innovation within engineering education along with challenges of using them in learning environments [3]. Due to the recent introduction of GenAI tools and their rapid development and integration in engineering education, new policies are needed to regulate their use [7], [8], [9], [10]. These policies should aim to preserve academic integrity while ensuring that access to GenAI tools is equitable for all students. This paper conducts a literature review of research in relevant fields that discuss the role of GenAI tools, such as ChatGPT and others in engineering education, highlighting some of the recurring themes on this topic.

Background and Motivation

AI has been a large part of our lives for many years, from recommendation systems to facial recognition models and other applications across different sectors [1]. Particularly in education, AI tools have a wide variety of use for students, educators and researchers. A literature review conducted by Chiu et al. discusses several areas where AI can be utilized in education [11]. Notable uses include assisting with students with tasks, analyzing feedback, helping educators enhance their teaching methods, providing adaptive teaching strategies, developing automatic feedback systems and other administrative tasks [11]. However, these use cases can be significantly enhanced with the use of GenAI and LLM tools. For example, previously the use of AI tools, such as GitHub Copilot allowed for code suggestions based on general trends in programming, as well as the style of writing code adopted by the developer [10]. With more recent versions of the same tool, enhanced with the power of GenAI, developers can interact with an AI chatbot that can perform tasks like writing unit tests.

There is a growing body of research on various applications of GenAI in engineering education. These topics include the use of GenAI by students and educators, their perspectives of these tools – their benefits, drawbacks, use cases and implications – ethical considerations and policies related to the use of GenAI tools, equity and academic integrity. As their capabilities increase, the list of such tools specializing in various tasks and their uses are growing at a rapid speed. Consequently, the amount of research in this area has been growing at a fast pace as well. The American Society of Engineering Education (ASEE) conference 2024 alone had 25+ submissions that directly mentions GenAI and Engineering education in their titles. However, due to the rapidly growing nature of this area, it is difficult to get a snapshot of the role GenAI plays in engineering education. There is a need for a framework that helps researchers in engineering education understand the range of topics discussed in this area, along with the stance of different researchers on this matter.

This study aims to fill that need by developing a framework to understand the current literature around the use of GenAI in engineering education, helping engineering educators and researchers identify emerging themes in this area. The findings from this study can be used to get

a snapshot of the current literature in this field without having to stay up to date on a large area of research. In doing so, the research questions we are trying to answer are:

1. What are the emerging themes in current literature surrounding the use of GenAI tools in engineering education?
2. What do researchers in this field have to say regarding the use of such tools in engineering education?

Methodology

This study includes a literature review of numerous papers in engineering education discussing the use of Generative AI tools, including some use cases (by both students and educators), the perspective of educators and students on these tools, as well as ethical and policy-related implications that may arise. Research papers are sourced for this literature review by searching through databases, such as the ASEE conference proceedings, google scholar, and the X university database. The keywords used for the search include "GenAI in engineering education", "Generative AI", "Generative Artificial Intelligence". The authors determined the relevance of each research output based on its abstract. Research that discusses the use of GenAI in engineering education and the aforementioned areas are selected, the rest are discarded. The selected papers are first classified into a few theme areas based on their title and abstracts. Next, the papers were analysed further to understand their contributions to this area and the main findings of those papers were separated into 6 theme areas listed in table 1.

Table 1: Theme areas from the literature review and corresponding topics from the research.

Theme areas	Description
Student perspective	Specific uses of GenAI among students, Student attitudes towards using GenAI, Student concerns on this topic
Instructor Perspective	Instructors' attitudes and perceptions of using GenAI
Using AI to enhance teaching and learning	Using AI to supplement learning, Specific uses on GenAI in engineering education, Evaluation of GenAI tools in engineering education, GenAI for feedback generation, Use of GenAI tools to build research skills, and The use of such tools in engineering education research.
Impacts of GenAI on EngEd	Implications of using GenAI tools in engineering education, along with the ethical and policy related considerations associated with their use.
Course and Curriculum Development	Integration of GenAI tools into the engineering courses and curricula and its implications
Other	Other themes not captured in the themes above.

Literature Review

Table 1 demonstrates that the papers selected for this literature review cover a wide range of topics, representative of the current research scene. The authors of the papers extracted the main findings of each paper, re-categorizing them into the themes above. The subsequent sections discuss the findings from these sources and how they are connected.

Use of GenAI: Students' Perspective

In recent years, studies in GenAI and education have placed students at the forefront of their research, analyzing how they use these tools and their attitudes toward them. Therefore, this literature review has dedicated a theme area to the students' perspective of GenAI in engineering education. Topics in this area include the capabilities of GenAI to assist students in their learning, as well as ethical concerns regarding its adoption.

Many researchers in engineering education have investigated ways in which students integrate GenAI tools in their learning, and how useful they can be. A major advantage of using GenAI tools in engineering education is the increase of students' access to information, retention of knowledge, and learning outcomes at a relatively lower cost (both financial and time) [7]. GenAI tools can have various applications in engineering education, including generating text with the use of LLMs, generating images using diffusion models, generative adversarial networks (GANs), and variational autoencoders (VAEs), or generating music using wavenet and other transformers architectures [12].

GenAI tools can bring significant innovations to engineering education, changing how engineering students learn – from helping solve complex problems to streamlining their tasks. A study conducted by Altares-López et al. in Madrid introduces secondary students to multimodal GenAI tools to investigate their perceptions of GenAI after participating in experiential learning activities involving these tools [12]. This study introduces students to GenAI tools for creative content generation and hands on applications, creating videos and other multimedia content using these tools [12]. However, in engineering education, the application of GenAI tools may be more geared towards assisting in discipline specific problem solving and enhancing their learning skills. A study conducted with undergraduate students by Camacho-Zuñiga et al. in México highlights several uses of GenAI tools ranging from assist students in brainstorming, to helping explain and contextualize concepts, streamlining workflows, assisting in writing academic documents, aiding in engineering problem solving, generating images, text, videos, code and more [5]. In another study conducted in the US, Camarillo et al. highlight additional uses of GenAI by Civil Engineering students, including assisting in gathering information for research and literature reviews, writing code, solving complex problems or performing calculations, data analysis, creating designs and modelling and supporting in decision making for civil infrastructure systems [9]. These studies highlight the ways in which the integration of GenAI tools in engineering education innovates teaching and learning practices in this field.

Despite the wide range of uses of GenAI tools in engineering education, the perception of GenAI in engineering education is divided among the students. While some students demonstrate openness and excitement for the innovations that GenAI tools can bring to engineering education, others are cautious, expressing concerns regarding issues around risks and challenges that these tools may impose [7], [13], [12]. A study conducted by Arowosegbe et al. at the University of Bolton highlights that many students are aware of GenAI tools in engineering education and have personal experience with these tools [7]. Although majority of their participants suggest that GenAI tools offers an "edge" when used for academic purposes, many express concerns regarding the integration of these tools in engineering education [7]. Similarly, Camarillo et al. highlight issues regarding ethical concerns regarding the consent to use AI, the acknowledgment of AI in course work, and the fairness and safety of AI in both educational and professional settings [9]. They express concerns regarding training civil engineers to rely on GenAI tools, since they have a direct responsibility for human health and safety as they design critical infrastructure. Additionally, literature raises concerns regarding the black-box nature of GenAI tools, the accountability and traceability of their outputs, and possibilities of students' critical thinking and problem-solving skills being halted due to their over-dependence on these tools [5], [13]. However, advancements in policies and guidelines regarding the use of GenAI tools, along with adequate training on proper uses of such tools can significantly mitigate these issues, helping students benefit from them throughout their engineering education journey [3], [5], [13], [9], [14].

Use of GenAI: Instructors' Perspective

Although students have a positive outlook on the use of GenAI in engineering education, the degree of utilization of these tools hinges upon the faculty's openness to them. Therefore, the perspective of course instructors is another area that has garnered significant research attention. This section discusses the findings of some research analyzing the faculties' perspective of GenAI tools in engineering education.

Similar to engineering students, many instructors were also divided in their perception of GenAI tools – some were supportive of their integration in engineering education, while others were against it [8]. Harper et al. conducted a qualitative study of engineering and computer science faculty members at Utah State University, who were divided in their perspectives of GenAI tools [8]. Although many – including some opposing participants – highlight that these tools can be very useful, they also agreed that they can be used incorrectly. Therefore, they also emphasized the importance of adequate training regarding the use of GenAI tools prior to integrating them in courses [8], [15]. A unique perspective that the instructors shared which was not mentioned by the students was this idea that these are "disruptive technologies" and should be treated as many others of this kind from the past [8]. This suggests that compared to engineering students, their faculty members are more cautious of GenAI tools.

Instructors also draw attention to concerns about the ethics and equity involved in the use of GenAI tools by students. They highlight issues related to ensuring equal access to GenAI tools for all students [8], [15]. Although most GenAI tools have free "tiers", allowing base level access to their capabilities, there are often additional "premium" features associated with paid memberships to these tools, providing students with additional benefits. Some faculty members raise concerns about whether the premium features of these tools should be made accessible to students and, if so, whether the responsibility for covering the costs should fall on individual students or their institutions [8].

Instructors have also highlighted many benefits of GenAI tools in engineering education, including researching and synthesizing information and helping explain and contextualize complex engineering concepts. However, while the capabilities of GenAI tools, such as ChatGPT is impressive, in certain highly specialized areas, the responses of these tools fall short and are not satisfactory [15]. This is also a sentiment shared by some student participants in some of the studies in this area. Overall, while the student concerns are mainly related to individual costs and benefits in the use of GenAI tools, the instructors' perspectives go beyond the individual and account for larger issues related to access, equity and ethics of GenAI tools.

Use of GenAI: Enhancing Teaching and Learning

Literature also discusses pedagogical shifts, suggesting that GenAI could fundamentally reshape curriculum design and classroom dynamics, prompting educators to reconsider how these tools can enhance learning experiences [3]. Both students and instructors have integrated GenAI tools in engineering education to enhance teaching and learning or streamline repetitive tasks. LLM based GenAI tools, such as ChatGPT can aid students in conducting research, complete calculations and perform other problem-solving tasks, including coding tasks and improving code snippets [16], [17]. This can improve their critical thinking skills, identify errors in AI generated content and improve their AI literacy by making them more familiar with the capabilities and shortcomings of GenAI tools. Santos et al. mention additional tools for coding for Information, Communication Technology (ICT) students, while also highlighting some ethical considerations, such as, addressing biases in AI outputs, ensuring transparency, responsible AI use, societal impacts, and ethical dilemmas [10]. With the integration of GenAI tools that are capable on providing real-time feedback, students can have personalized, interactive learning models. Additionally, assessments may need to shift from simple tasks that can easily be completed by GenAI tools, towards tasks that enable students to understand concepts and critically thinking about the outputs generated by GenAI. Both faculty and students need to be informed of the capabilities and limitations of GenAI, effective GenAI uses to integrate them into their teaching and learning methods respectively [10]. Additionally, policies will need to be adapted to promote responsible AI usage and equitable access to GenAI tools [10], [17]. Overall, while GenAI is a revolutionary technology with the potential to enhance teaching and learning in engineering education, there ought to be policies and guardrails in place to ensure ethical and equitable use.

GenAI tools are particularly useful in software and computer engineering and computer science education, where programming is a significant part of the curriculum. In addition to chat-based systems, such as ChatGPT, there are additional tools that are useful when coding, such as GitHub Copilot, Amazon CodeWisperer. These technologies are powered by large language, generative models with the ability to use common patterns in code and contexts within the file to suggest code snippets that may be useful to the students. These tools can help beginner and expert students with their programming tasks and improve their programming skills by suggesting syntax corrections, alternative implementations, and efficiency improvements. Zhong et al. compare the performance of different GenAI tools in Electrical Engineering and find that GPT-4 provided better programming explanations and code snippets than Google Bard [18]. Additionally, they suggest that students who refined their prompts received more relevant code suggestions [18]. AI tools can also accelerate the development of repetitive functions, API calls, and data structures using automatically generating boilerplate code, which is especially useful in areas of software engineering where there are a lot of starter code, such as developing web applications [10]. Even outside of software engineering, there are other fields of engineering that may require some degree of coding, particularly using MATLAB. Cortez et al. highlight that AI helps students identify bugs and suggests fixes by explaining error messages and debugging strategies [19]. Additionally, it can also help explain logical errors in MATLAB, which can help students learn more about debugging their programs. GenAI tools are particularly useful for semantic error feedback, guiding students toward the correct solution without giving direct answers [20]. However, all the benefits of GenAI in helping students with coding also comes with certain challenges. For instance, students may become over-reliant on the AI-generated code and never seek to understand the logic or read the documentations to learn how the libraries and functions operate [8]. Additionally, AI models may generate incorrect or inefficient code for complex problems, which can affect students' quality of work [18]. And lastly, there are concerns around plagiarism and code-ownership, for which researchers stress the need for clear course policies on AI-assisted coding [4]. Addressing these concerns with updated policies, course structures and assessments to adapt to the use of GenAI tools in engineering education can help ensure a fair, more effective integration of these tools.

LLMs and Prompt Engineering in Engineering Education

Chat based GenAI tools, such as ChatGPT contribute largely Engineering Education in multiple ways, including learning enhancement, creativity stimulation, research support, and ethical considerations [8], [16]. LLM technologies used in engineering education include chat-based technologies, such as ChatGPT, Microsoft Copilot, Google Bard (Gemini) that students can hold conversations with. Additionally, there are other technologies that are not chat-based, such as GitHub Copilot, Amazon CodeWhisperer, or other LLM based tools that can execute specific tasks, more commonly to generate code based on context, common patterns and the syntax of the programming language used by students.

Chat-based GenAI tools are predominantly based on Generative Pre-trained Transformers, which uses deep learning to generate a sequence of text, code, or other data based on a "prompt" fed into the model by the user [21]. The model is trained on a large database on unlabeled text from numerous sources, including Wikipedia, and other sources, mainly in English. Using this knowledge, the model can understand human text input and produce human-like text-based output. Fatahi et al. highlight that ChatGPT can act as a virtual tutor, providing students with explanations, answering questions, and helping them understand complex engineering concepts [16]. Faculty members from a study conducted by Harper et al. benefit leverage ChatGPT in engineering education to grade assignments, evaluate student performance, and identify plagiarism in addition to helping educators refine their teaching methods [8, 6]. Overall, these chat-based tools can increase accessibility of information, enhance creativity, and provide real-time feedback, making learning more engaging and interactive. However, since the output of these tools depend on the user input, or prompts, they require some degree of fine-tuning, or prompt [22]. Prompt engineering is used to develop effective inputs for chat-based GenAI tools to help them produce more accurate and relevant responses. Crafting an effective prompt that produces the desired outcomes is a skill to develop when integrating these chat-based GenAI tools in engineering education. Additionally, a well-crafted prompt encourages students to think more critically when solving problems and helps mitigate hallucinations and misleading AI-generated content. Fatahi et al. suggest that students who refined their prompts iteratively received better responses in programming tasks [16]. Similarly, Kyul Kim et al. find that students participants who craft detailed prompts produce higher-quality, more creative ideas compared to those who use generic ones, further suggesting the importance of developing effective prompts [23].

Some authors also highlight common challenges in prompt engineering, including lack of AI literacy, hallucinations, bias in responses, and over reliance on AI tools [4], [18] [19]. If students lack AI literacy and are unfamiliar with the basics of how the GenAI tools work, they are prone to writing prompts that are inadequate and may result in responses that are inaccurate or irrelevant. Cortez et al. initially found that students who are unfamiliar with AI technologies, tend to write vague prompts, reducing the effectiveness of the AI responses [19]. As a result, students find that ChatGPT sometimes fabricates technical details when asked vague or open-ended questions [18]. Therefore, researchers also suggest techniques to write effective prompts to adequately leverage the capabilities of these technologies, including:

- **Using clear and specific prompts:** Breaking down complex requests into smaller parts and providing context, constraints, and objectives [23]. Instead of asking "Generate a product idea for COVID-19 prevention", ask "Suggest a low-cost wearable device that prevents COVID-19 transmission in crowded spaces. Consider portability and ease of use."
- **Iterating and refining prompts:** Starting with a general prompt, reviewing the AI's response, and iterative by adjusting the prompts for specificity [20].

- **Using constraints to guide the AI:** Limiting responses by word count, format, or structure [17]. Instead of asking “Summarize this paper on deep learning", refining the prompt to be "Provide a 100-word summary focusing on applications of deep learning in medical diagnosis."
- **Experimenting with different models:** Some models perform better at certain tasks than others. For example, at the time of writing this paper, Microsoft Copilot has a limit on the size of a file that is much smaller than that of ChatGPT. So, it helps to try out different models to see which one is better at specific tasks [18].

Effective prompt engineering is key to maximizing the benefits of ChatGPT and other AI tools in engineering education. Teaching students how to structure, refine, and critically assess AI-generated responses will ensure AI enhances learning without diminishing essential problem-solving skills.

Discussion

This literature review highlights the transformative potential of GenAI in enhancing teaching and learning practices in engineering education, along with the complexities and challenges associated with its adoption. By addressing the research questions, this discussion synthesizes emerging themes in the literature and explores the perspectives of researchers in the field, providing a comprehensive view of the role of GenAI in engineering education.

Emerging Themes in the Literature

In response to the first research question, the review identifies several key themes in the current literature on GenAI in engineering education. These include the multitudes of opportunities GenAI tools offer for enhancing teaching and learning in engineering education. Literature in engineering education highlights that with the help of GenAI tools, students can benefit from improved access to information, personalized learning experiences, and support for complex problem-solving tasks. Additionally, the literature emphasizes GenAI’s role in streamlining repetitive tasks, helping instructors improve the delivery of course content, and facilitate research and synthesis of information. However, recurring themes also highlight significant challenges with the adoption of GenAI, particularly in ethics, equity, and over-reliance. While students and instructors see potential benefits, they also express concerns about misuse, biases, and inequitable access to GenAI tools. For example, students’ critical thinking and problem-solving skills may be impacted if they over-rely on GenAI. Instructors, on the other hand, highlight concerns about disparities in access to GenAI tools, which could exacerbate inequities in education. These findings underscore the need for policies that balance innovation with accountability and inclusivity.

Researcher Perspectives on GenAI

Addressing the second research question, researchers in this field provide nuanced insights into the use of GenAI tools in engineering education. While they acknowledge the transformative potential of GenAI, they also emphasize the importance of addressing issues such as biases in AI outputs, the transparency of GenAI systems, and the accountability of AI-informed decisions, particularly in fields like civil engineering where public safety is a concern. Researchers also call for equitable access to these tools, noting that disparities in access to premium features could exacerbate existing inequities in education. Furthermore, they stress the need for evolving assessment methods, adequate training for both students and instructors, and institutional policies that facilitate responsible and inclusive GenAI integration.

Researchers also highlight that the integration of GenAI tools in engineering education represents a cultural shift in how engineering education is delivered and experienced. Both students and instructors must adapt to new roles as students need to become critical evaluators of AI-generated content, while instructors must transition from traditional teaching methods to roles as facilitators of AI-supported learning. This shift requires adequate training for both groups to develop AI literacy, understand the limitations of GenAI, and use these tools effectively. Lastly, some researchers propose that assessments in engineering education may need to evolve. Traditional evaluation methods that focus on simple problem-solving tasks may no longer be sufficient in the context of GenAI. Instead, assessments should emphasize critical thinking, creativity, and the ability to contextualize and interpret AI-generated outputs.

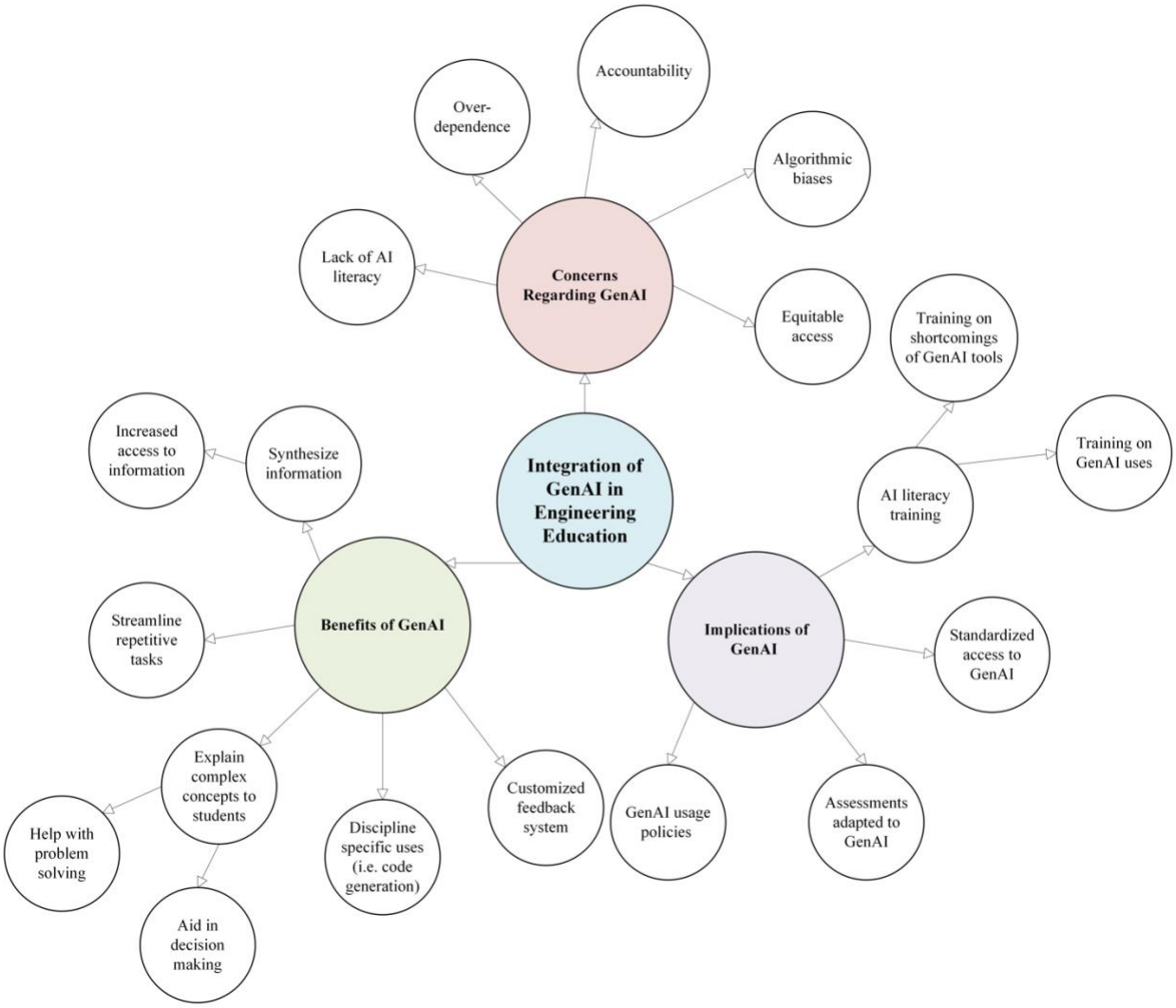

Figure 1: Emerging themes around the use of GenAI in engineering education.

By connecting these themes and perspectives, this discussion highlights the broader implications of GenAI adoption in engineering education for various stakeholders. Addressing the identified challenges and leveraging the opportunities will require collaboration among students, instructors, institutions, and policymakers to create an equitable, ethical, and innovative educational environment.

Next Steps

The findings from this literature review suggest that effective integration of GenAI in engineering education requires an in-depth approach that considers many stakeholders. Institutions and policymakers must collaborate to create guidelines that address ethical concerns, promote equity, and standardize training on the effective use of GenAI tools. Additionally, further research is needed to understand the long-term impacts of GenAI on learning outcomes, student skill development, and professional readiness. Institutions must also invest in

infrastructure and support systems to facilitate the responsible use of GenAI. This includes developing AI literacy programs for students and faculty, updating curriculum designs to incorporate AI capabilities, and ensuring that assessments are aligned with the skills required in an AI-integrated engineering workforce.

Conclusion

This study provides a snapshot of the current landscape of GenAI use in undergraduate engineering education. Additionally, it supports the development of a framework for understanding the applications of GenAI tools in undergraduate engineering education and its implications. This research identifies approaches that may be effective and transferable, and can inform future research, policy development, and instructional practices around the integration of GenAI tools in engineering education. GenAI tools hold immense potential to revolutionize engineering education, fostering innovation in teaching and learning. However, their integration must be approached thoughtfully, with a focus on addressing ethical challenges, ensuring equitable access, and preparing students and instructors to use these tools responsibly. By balancing opportunities with challenges, stakeholders can leverage GenAI to enhance the quality and inclusivity of engineering education, ultimately preparing students for a rapidly evolving technological landscape.

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