Generative Artificial Intelligence in Undergraduate Engineering: A Systematic Literature Review

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Hudson Harris is a first-year biomedical engineering student at the University of Oklahoma. Fascinated by the potential implications of artificial intelligence (AI) in the coming years, Hudson authored this paper to capture a snapshot of current research on generative AI within undergraduate engineering. This work aims to serve as a foundational resource for ongoing academic discourse and future developments. Hudson's interest in the intersection of AI and biomedical engineering drives his academic pursuits, seeking to explore how these technologies can revolutionize both fields

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Abstract

The dawn of the Fourth Industrial Revolution has ushered in an era where the fusion of digital, physical, and biological worlds is increasingly evident. In this evolving landscape, Artificial Intelligence (AI) has emerged as a major force, reshaping traditional boundaries across various domains. While industry advancements in AI are rapid, the academic realm, responsible for nurturing the future workforce, seems to be progressing at a varied pace. Particularly in the foundational undergraduate years, the urgency to embed AI into the curriculum is pressing.

By methodically reviewing existing literature, we aim to offer a cohesive view of generative AI in undergraduate engineering. The overarching goal is to provide actionable insights to educators, policymakers, and curriculum architects, ensuring that future engineers are not only well-versed in their core disciplines but also adept in leveraging AI's expansive capabilities. This research study answers the following research question, "What is the current state, trends, and future of generative AI in undergraduate engineering?" and this will be accomplished through a systematic literature review (SLR).

The SLR included the following phases (I) Explore different academic databases including Google Scholar, IEEE Explorer, Web of Science, Engineering Village, ERIC, Science Direct, and Wiley Online Library to retrieve articles using the search terms. The search terms include Generative AI or Artificial Intelligence + College + Engineering, AI, or Artificial Intelligence + Engineering, Chat GPT + engineering + education, and Undergraduate artificial intelligence. (II) Screening the abstracts and full text of the articles to eliminate papers beyond the research topic's scope. Exclusion criteria such as EC 1: Articles written before 2013, EC 2: Articles not written in English, EC3: Articles not pertaining to engineering, EC 4: Articles not pertaining to generative AI excluding Chat GPT (Deep learning, text generation, vast data input), were used. EC 5: Articles not pertaining to undergraduate engineering EC 6: Articles not pertaining to higher education EC7: Articles not pertaining to traditional Artificial intelligence / machine learning EC 8: Article is a work in progress. EC 9: Articles pertaining exclusively to the teaching of deep learning algorithms (III) The articles that made it to the final phase were reviewed in detail. (IV) This information was consolidated, synthesized, and examined to find the emergent themes.

***Keywords*:** ChatGPT, engineering education, GenAI, large language models, undergraduate engineering

Introduction

The dawn of the Fourth Industrial Revolution heralds an unprecedented era of technological convergence, where the integration of digital, physical, and biological systems becomes a defining characteristic of societal and economic transformations. Artificial Intelligence (AI), especially generative AI, stands at the vanguard of this revolution, driving innovations that blur the traditional boundaries across various domains, including engineering education [1-2]. The contrast between the swift AI advancements in the industry and the varied pace of academic progression underscores the urgent need for embedding AI into undergraduate engineering curricula. This discrepancy not only highlights the challenges inherent in updating academic programs but also emphasizes the critical role of academia in preparing a workforce capable of navigating and contributing to an AI-driven future [3].

Recent literature emphasizes AI's burgeoning role in education, predicting a profound impact on pedagogical methods and learning outcomes. Despite this growing recognition, there remains a significant gap in research specifically targeting the integration of generative AI within undergraduate engineering education. By undertaking a systematic literature review, this study aims to fill this gap, providing a nuanced understanding of generative AI's current applications, challenges, and future potential in engineering education.[4] The goal is to equip educators, policymakers, and curriculum architects with a solid foundation to innovate curricula that not only meet but anticipate the needs of the engineering profession in an AI-centric world [4-7].

The evolving industrial landscape, increasingly defined by AI's integration into core engineering practices, demands a reevaluation of educational strategies. Traditional pedagogical models must evolve to incorporate curricula that are both adaptive and anticipatory of rapid technological advancements. Generative AI, with its unparalleled capabilities for creating new content, problem-solving, and driving innovation, offers untapped potential for educational reform. Its application in engineering education could fundamentally alter how students engage with complex concepts, fostering environments that are more interactive, personalized, and conducive to deeper learning [8-10].

However, the path to integrating generative AI into engineering curricula is fraught with challenges. Ethical considerations, the quality and bias of AI-generated content, and the preparedness of both educators and students to engage with this new paradigm are critical issues that must be addressed. This study, by focusing on the multifaceted aspects of generative AI's role in undergraduate engineering education, seeks to navigate these challenges, offering a comprehensive analysis that informs future educational practices and policy decisions [11].

In navigating the intricacies of integrating generative AI into undergraduate engineering education, this study seeks to uncover not only the potentialities and hurdles but also the broader implications for pedagogy, curriculum development, and industry alignment. By posing the research question, 'What is the current state, trends, and future of generative AI in undergraduate engineering education?', we delve into a comprehensive inquiry aimed at bridging existing gaps.

Methods

The Systematic Literature Review (SLR) process was initiated by applying a range of search terms across various academic databases, following the approach outlined in existing SLR

methodologies [12-14]. A total of seven search phrases were utilized in this study: "Generative AI or Artificial Intelligence + undergraduate + Engineering," "AI or Artificial Intelligence + undergraduate + Engineering," "Chat GPT + engineering + undergraduate," "Chat GPT + first year engineering," "AI applications in undergraduate engineering," "Machine learning in undergraduate engineering," and "Generative AI for engineering teaching." These terms were specifically chosen to capture the multifaceted nature of generative AI in the context of undergraduate engineering education. The databases employed for this search included Google Scholar, Web of Science, IEEE Xplore, Compendex/Engineering Village, ERIC - Advanced Search: EBSCOhost, ScienceDirect, and Wiley Online Library. Each database was selected for its comprehensive coverage of scholarly articles relevant to engineering, artificial intelligence, and education. The SLR process and structure/format used in this paper was referred from several existing SLR studies [12-14].

Data Collection

The data collection process for the systematic literature review was meticulously orchestrated to ensure a comprehensive examination of the relevant literature on generative artificial intelligence in undergraduate engineering education. The multi-stage selection process is depicted in Figure 1. Initially, 554 articles were identified from seven academic databases using the specified search terms. The number of articles retrieved from each database was as follows: Google Scholar (n=196), Web of Science (n=66), IEEE Xplore (n=78), Engineering Village (n=111), EBSCOhost (n=13), and ScienceDirect (n=59). Wiley Online Library (n=38).

Data Analysis

Following the retrieval, duplicate articles were removed, resulting in a refined set of 370 articles. These articles were first screened by abstract, to eliminate articles not pertinent to the study we used nine exclusionary criteria **EC 1:** Articles written before 2013 **EC 2:** Articles not written in English **EC3:** Articles not pertaining to engineering **EC 4:** Articles not pertaining to generative AI excluding Chat GPT (Deep learning, text generation, vast data input) **EC 5:** Articles not pertaining to undergraduate engineering **EC 6**: Articles not pertaining to higher education **EC 7**: Articles not pertaining to traditional Artificial intelligence / machine learning **EC 8**: Article is a work in progress. **EC 9:** Articles pertaining exclusively to the teaching of deep learning algorithms.

After the comprehensive screening process, which resulted in the exclusion of 181 articles for not meeting the study's criteria and another 164 articles were removed after full-text review, 24 articles remained. These articles constituted the core of the literature synthesized in the review. As the review progressed, the final articles were analyzed to align with the existing codes or to identify new emergent patterns, necessitating the creation of supplementary codes. These codes were then amalgamated into broader themes that represented the key dimensions of generative AI within undergraduate engineering education.

In the final phase of the analysis, a detailed summarization and thematic categorization of the remaining articles. The findings from this extensive data analysis are organized into two parts. The first part uses descriptive statistics to highlight trends across the articles. The second part conducts a qualitative review of the identified themes, offering an in-depth look at the relationship between generative Artificial Intelligence and undergraduate engineering education.

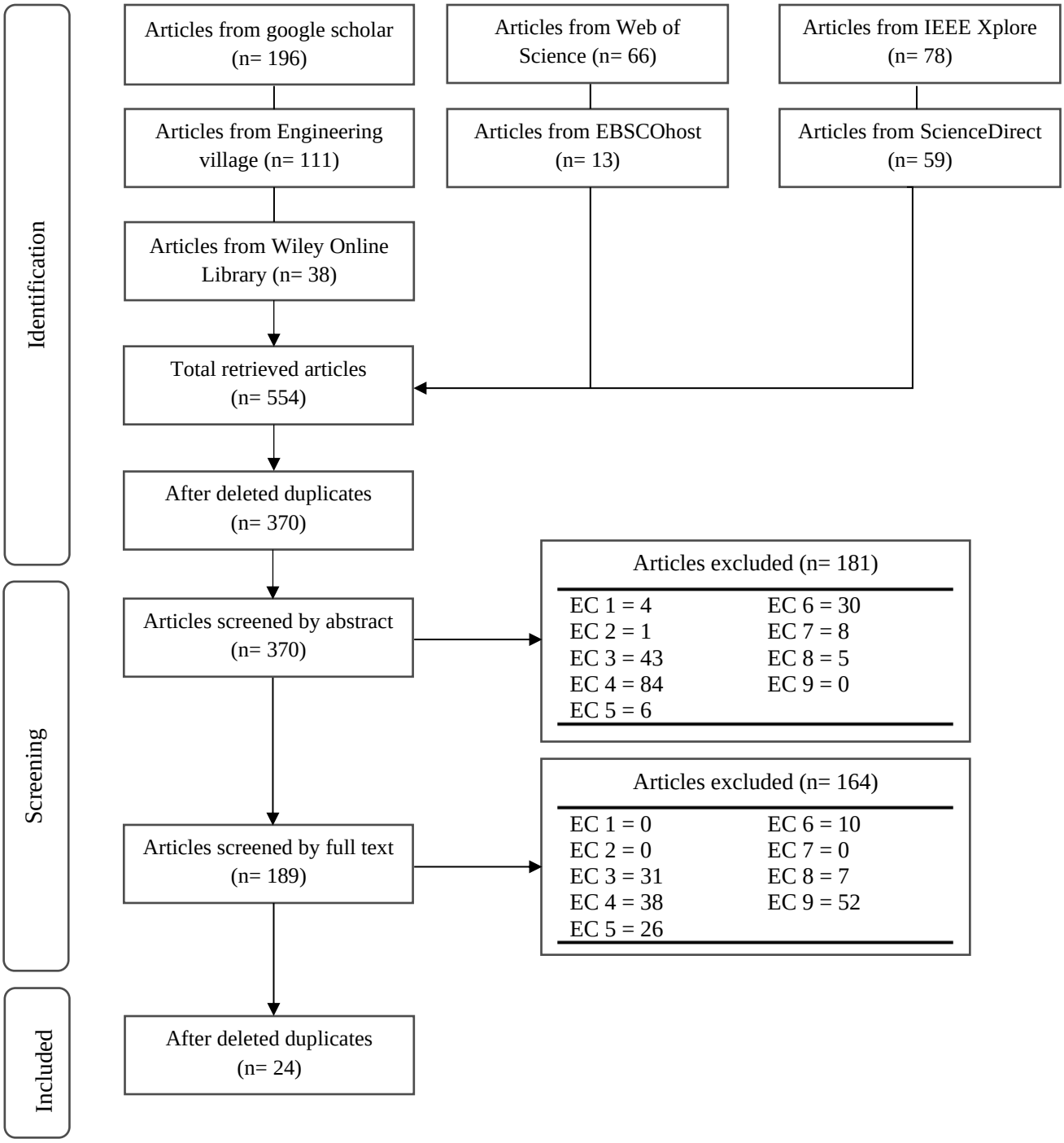

Figure 1: Systematic Literature Review Article Selection Process

Strengths and Limitations

The systematic literature review (SLR) conducted for this research offers a comprehensive overview of the use of generative AI in undergraduate engineering education. By synthesizing the

literature, this study has illuminated the current state and trends within the field, providing a clear framework of themes that are instrumental for both practitioners and researchers. These themes are augmented with practical implications and avenues for future research, offering targeted guidance to those in the domain of engineering education. One of the primary strengths of this SLR is its exhaustive nature. No other review on this specific intersection of generative AI and undergraduate engineering education was identified, which underscores the novelty and contribution of this research. The findings enhance the existing body of knowledge, pinpointing the strengths of prior studies and highlighting potential areas for future inquiry.

However, the research approach employed in this SLR does encounter certain limitations. Firstly, the selection of articles was governed by exclusion criteria, which did not account for the quality or distinctiveness of the content. The reliance on seven databases were intended to mitigate this by covering a broad spectrum of potentially relevant journal and conference articles. While this approach aligns with other SLRs in engineering education, the exclusion of books and technical reports may have narrowed the research's scope. Secondly, the search terms were carefully chosen to capture the nexus of undergraduate engineering education and generative AI. It is possible that alternative search term combinations, or the inclusion of additional terms, might have yielded additional relevant literature. Lastly, the limitation to English-language articles may have resulted in a partial view of the global research landscape, as valuable insights from non-English sources remain unexplored. This language restriction could have implications for the comprehensiveness of the international perspectives and practices captured in this review.

In sum, while this SLR has established a solid foundation for understanding the integration of generative AI in undergraduate engineering education, the limitations suggest caution in generalizing the findings and point to the need for ongoing research to fill the identified gaps.

Findings

Descriptive Findings Related to Publication Trends

***Publications Per Year*:** An analysis of the period from 2018 to 2023 reveals a notable trend in the publication of articles on generative AI in undergraduate engineering education. Initially, publications were sparse, with a single article in 2018, followed by a slight uptick to two articles in 2019. Interestingly, there was a lull in 2020 with no articles published, which could be attributed to a variety of external factors affecting academic research output globally. However, a steady recovery is observed with one publication each in 2021 and 2022, culminating in a significant surge to nineteen articles in 2023. This dramatic increase reflects a burgeoning interest and a possible inflection point in research on generative AI applications within the realm of engineering education, possibly propelled by increased digitalization and technological dependence in learning environments post-2020. Such a trend not only signifies a growing scholarly focus on integrating AI into engineering pedagogy but also suggests a robust engagement from the academic community in harnessing AI's potential to redefine educational paradigms.

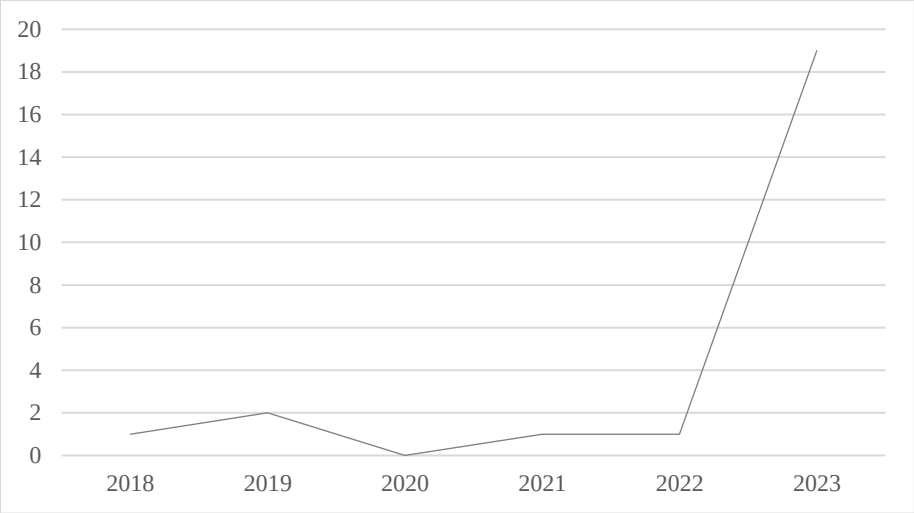

Figure 2: Line graph of final articles published by year

Publication type and publication outlet

Out of the 24 articles reviewed, the majority, totaling 14 articles, equating to 58.33%, were published in academic journals. This suggests a preference for the peer-review process and the academic rigor associated with journal publications in disseminating research findings in this field. Conferences also played a significant role in the proliferation of knowledge, with 6 articles, or 25%, appearing in conference proceedings. This reflects the importance of conferences as a platform for immediate scholarly exchange and for presenting preliminary findings to the academic community. Lastly, 'Other' publication outlets accounted for 4 of the articles, making up 16.67%. This category may include white papers, reports, book chapters, or other forms of grey literature, which often provide a more accessible avenue for the dissemination of practical implications and applied research findings.

Country Affiliation of First Author

Table 1 shows the geographical diversity of the first authors whose works were included in our review, representing fourteen different countries. The United States emerged as the leading contributor, with 16.67% of the articles, followed by notable representations from China, Taiwan, Turkey, and the United Arab Emirates, each offering a significant share of 4.17% to 8.33%. The distribution reflects a strong influence of U.S.-based research in the domain of generative AI in undergraduate engineering education. However, this distribution could be somewhat skewed, given that our review was limited to English-language articles. It is also important to consider that while other regions may actively participate in Generative AI research, varying local pressures, incentives, or publication infrastructures might affect their visibility within the international academic publishing arena.

Variety of Engineering Disciplines in Reviewed Literature

Table 2 delineates the range of engineering disciplines that the selected articles encompass. The survey of literature revealed that Multi-disciplinary Engineering had the highest representation at 25%, indicating a strong interest in generative AI applications across various engineering fields. Computer Science followed closely, constituting 20.83% of the articles, underscoring its integral role in the development and research of AI technologies. Systems Engineering and 'Not specified'

categories were also notably represented, each accounting for 12.50%, reflecting the broad applicability and interest in generative AI within these areas. Other specialized disciplines such as Electrical, Mechanical, Biomedical, Chemical Engineering, Material Science, and Information Sciences, each contributed to 4.17% of the articles, highlighting the widespread engagement with generative AI across diverse engineering sectors. These findings emphasize the versatility and expansive reach of generative AI within engineering education, with implications for a wide array of subfields. The adoption and study of generative AI in these various disciplines suggests its growing significance and potential for transformative impact in engineering education at large.

Table 1: Distribution of Country Affiliations of First Author

#	Country of first author	Frequency	Percentage (%)
1	United states	5	16.67
2	Belgium	2	8.33
3	Australia	2	8.33
4	Turkey	2	8.33
5	United Kingdom	2	8.33
6	United Arab Emirates	2	8.33
7	China	1	4.17
8	Israel	1	4.17
9	Spain	1	4.17
10	Canada	1	4.17
11	India	1	4.17
12	Taiwan	1	4.17
13	Qatar	1	4.17
14	Germany	1	4.17
15	Nigeria	1	4.17

Table 2: Distribution of discipline

#	Discipline	Frequency	Percentage
1	Multi-disciplinary engineering	6	25.00
2	Computer science	5	20.83
3	Not specified	3	12.50
4	Systems engineering	3	12.50
5	Chemical engineering	2	8.33
6	Biomedical Engineering	1	4.17
7	Electrical engineering	1	4.17
8	Material science	1	4.17
9	Information sciences	1	4.17
10	Mechanical engineering	1	4.17

Variety of artificial intelligence in reviewed literature

Table 3 offers a clear depiction of the research focus within the field of generative artificial intelligence (AI) as applied to undergraduate engineering education. It reveals that a substantial portion of the literature, 37.50%, addresses Machine Learning (ML) and broader AI concepts without a specific emphasis on generative models. These studies typically investigate the potential of AI to enrich educational methodologies, suggesting a foundational interest in the integration of

AI within pedagogical frameworks. The table also highlights that a significant corpus, 29.17%, explores General Applications of Generative AI, examining its transformative effects across disciplines. This is indicative of an academic movement towards embracing the generative aspect of AI for its innovative capabilities. Research specifically centered on ChatGPT comprises 25.00% of the articles, underscoring the model's rising prominence and its implications for academic integrity and pedagogical innovation. Lastly, studies exploring Other Large Language Models (LLMs) represent 8.33%, pointing to an expanding interest in a variety of advanced AI tools beyond ChatGPT. Collectively, these categorizations underscore the diverse yet interconnected avenues of AI research, reflecting its broad applicability and the growing recognition of its potential to revolutionize engineering education.

Table 3: Categorization of articles based on type of artificial intelligence focused upon

#	Type	Definition	*N*	%
1	Machine Learning (ML) and AI in Education (non-Generative Focus)	This category comprises studies that address the application of machine learning (ML) and broader artificial intelligence (AI) concepts in educational settings. It does not specifically focus on generative models but rather on the use of AI and ML for enhancing educational practices, including pedagogical strategies, curriculum development, ethical considerations, and the development of analytical and problem-solving skills.	9	37.50
2	General Applications of Generative AI (GenAI)	This category refers to the subset of artificial intelligence that includes algorithms and models capable of generating novel content. This category encompasses studies that explore the broad applications, ethical considerations, and transformative potential of GenAI across various disciplines, assessing its implications for innovation, productivity, and societal impact.	7	29.17
3	Specifically focused on ChatGPT	This category is dedicated to research that specifically examines ChatGPT, an advanced language model developed by OpenAI. Papers in this group delve into ChatGPT's capabilities, its role in educational settings, performance benchmarks, and its broader impact on areas such as academic integrity, teaching methodologies, and learning outcomes.	6	25.00
4	Other Large Language Models (LLMs)	Included in this category are papers that investigate Large Language Models (LLMs) other than ChatGPT. These works typically focus on the educational integration, application potential, and challenges posed by various LLMs, considering their capacity for natural language processing and generation within academic and practical contexts.	2	8.33

Themes

Thematic Analysis: Descriptions, Exemplars, and Implications

In this segment, we dissect the five themes identified through a meticulous analysis: AI integration in education, ethical considerations, AI's role in personalized learning, challenges of AI in education, and its future implications. Each theme is defined, and its relevance is explained through the lens of the articles associated with it. We highlight two seminal studies for each theme that exemplify the core of the theme's subject matter, based on their focused approach compared to other articles within the same category. The distribution of articles is summarized in Table 4 which

categorizes them according to the thematic classification, correlating to specific codes derived from the literature. It is noteworthy that articles may intersect across multiple themes.

Table 4: Theme definition and number of articles included

	Definition	**Codes**	***N***
AI Integration in the field of Engineering	This theme examines the transformative role of AI in engineering, highlighting how AI tools like intelligent tutoring systems and language models are incorporated into teaching and learning processes, and the impact of AI on curriculum design and pedagogical approaches.	AI in course Course content AI teaching	7
Ethical and Academic Integrity Considerations:	This theme explores the ethical challenges and academic integrity issues arising from the use of AI in educational contexts. It focuses on concerns like AI's potential for misinformation, the need for human supervision in AI-assisted learning, and the balance between technological reliance and human expertise.	Ethics Academic integrity Assessment's Administration	7
AI's Role in Personalized Learning and Assessment	This theme addresses how AI technologies facilitate personalized learning experiences and revolutionize assessment methods. It covers AI's capabilities in tailoring educational content to individual needs, automating assessments, and providing real-time, customized feedback to optimize learning outcomes.	Tutoring Personalized learning Out of classroom	3
Challenges and Limitations of AI in Education	This theme critically examines the limitations and challenges inherent in AI's use in educational settings, particularly in complex subjects like engineering. It discusses AI's limitations in understanding nuanced content, the potential for misinformation, and the need to balance AI tools with traditional educational methods.	Challenges Limitations Misnomers	3
Future of AI in Engineering Education	This theme focuses on the future implications and advancements of AI in engineering education. It explores potential developments in AI technologies, their role in shaping educational methodologies, and the evolving challenges and opportunities in integrating AI into teaching and learning processes.	Future changes Future of learning	4

Theme 1: AI Integration in the Field of Engineering

Artificial Intelligence (AI) is rapidly emerging as a transformative force in, heralding a paradigm shift in pedagogical strategies and curriculum development. Within this innovative educational framework, AI tools such as intelligent tutoring systems, personalized learning modules, and advanced language models are being woven into the fabric of engineering disciplines, including chemical engineering, material science, nanotechnology, and mechanical engineering. The papers selected for this theme collectively examine the multifaceted role of AI in reshaping educational methodologies, thereby enriching the learning experience and fostering a more interactive and engaging environment for students.

The integration of AI in education is not merely a technological upgrade but a comprehensive rethinking of how educational content is delivered and processed. The papers scrutinize the current

landscape and speculate on the future trajectory of AI in engineering education, shedding light on AI's potential to bridge skill gaps, promote interdisciplinary studies, and adapt to the rapidly evolving digital world. For instance, [1] provides a systematic review of AI applications in higher education, questioning the readiness of educators in the face of AI advancements. Similarly, [2] delve into the multifaceted implications of AI for engineering assessment, while [3] discuss the innovative use of large language models in chemical engineering education.

Exemplar studies within this theme underscore the practical applications of AI tools and the nuanced understanding required to implement them effectively. For example, the use of ChatGPT to build core course problem models in chemical engineering highlights the model's prowess in enhancing problem-solving skills and preparing students for the demands of Industry 4.0 [3] Another study highlights the incorporation of ChatGPT into material science and nanotechnology education, emphasizing its role in assisting with coding assignments, data analysis, and exam preparation [5]. These studies point towards a future where AI tools do not replace educators but rather augment their ability to deliver complex concepts in more digestible, interactive formats. The transition towards AI-assisted education promises a wealth of opportunities to enrich student learning, provided that the tools are implemented thoughtfully, with an emphasis on maintaining academic integrity and the quality of the educational experience.

Exemplar Studies

In exploring the theme of AI Integration in the Field of Engineering, two studies stand out for their contribution and relevance. The first, conducted by [3] delves into the utilization of ChatGPT in chemical engineering education. Their empirical research focuses on enhancing problem-solving skills and providing a deeper understanding of core subjects through the application of ChatGPT in building virtual models for chemical engineering problems. This approach not only integrates programming into the curriculum but also prepares students for the demands of Industry 4.0. However, the study identifies several challenges, such as errors in the Large Language Models (LLMs) and limitations in computational capabilities. These issues underscore the importance of effective communication and clear task descriptions to overcome student isolation and inadequate feedback mechanisms, which are crucial for the successful implementation of AI tools in engineering education.

Another significant study in this theme is by [5], which investigates the use of ChatGPT as a teaching and learning tool in Material Science and Nanotechnology Engineering Education. This qualitative study evaluates ChatGPT's effectiveness in assisting with coding assignments, data analysis, and generating exam questions. The research highlights the potential of ChatGPT as an educational tool, particularly for complex nanotechnological concepts. However, the study also points out that while ChatGPT can be a valuable resource, its limitations necessitate it being used as an aid rather than a replacement for traditional teaching methods. The findings from [5] suggest that iterative interactions with ChatGPT are necessary to refine its utility, emphasizing the critical role of educators in guiding its use.

Research Implications

The study by [3] shows the importance of embedding AI technologies like Chat-GPT into engineering curricula to ensure students are well-prepared for Industry 4.0 demands. Further research is necessary to systematically assess how the incorporation of such AI tools affects student learning outcomes and to identify best practices for integrating these technologies into

educational programs. Additionally, [6] highlights the need for ongoing investigations into the multidisciplinary applications of AI in engineering education, suggesting that understanding the full scope of AI's capabilities and its impact on both teaching and learning is crucial.

Practice Implications

In practice, the findings from [5] imply that educators must consider iterative interactions with AI tools to refine their utility in teaching complex engineering concepts. The emphasis on the significant role of instructors in guiding the use of AI suggests that while AI can enhance the educational experience, it should be viewed as an aid rather than a replacement for traditional teaching methods [3] also indicate that effective communication and clear task descriptions are essential in overcoming challenges such as student isolation and inadequate feedback mechanisms, which are vital for successful AI integration in engineering education.

Theme 2: Ethical and Academic Integrity Considerations in AI Applications in Educational Settings

The integration of AI in educational settings, specifically in engineering education, brings forth significant ethical and academic integrity considerations. This theme explores the multifaceted role of AI in reshaping educational methodologies and the accompanying ethical challenges, as highlighted in a range of studies. These challenges include issues related to data privacy, bias in AI algorithms, equitable access to technology, and maintaining academic integrity in AI-assisted learning environments. The selected papers for this theme collectively examine the ethical implications of AI use in education, focusing on aspects such as the potential for AI to inadvertently promote academic dishonesty, create new forms of plagiarism, exacerbate existing biases, or foster new ones. This theme also delves into the responsibilities of educators and institutions in implementing AI tools responsibly. Key references include [1] on AI applications in higher education, [2] on the assessment integrity of AI in engineering education, and [3] discussing large language models in chemical engineering education.

Exemplar Studies

For the theme "Ethical and Academic Integrity Considerations in AI Applications in Educational Settings," the exemplar studies by [11] and [17] offer critical insights. [11] research centers around an analysis of engineering students' responses to an AI ethics scenario. This study is pivotal in measuring how engineering undergraduates navigate ethical challenges presented by AI, specifically in the context of facial recognition technology. It utilizes survey responses to gauge students' ability to identify and mitigate ethical dilemmas, revealing a critical gap in connecting technical solutions to broader ethical implications. This finding underscores the necessity for comprehensive AI ethics education among future engineers, highlighting the importance of integrating ethical reasoning and sociotechnical considerations into technical education.

In a similar vein, the study conducted by [17] investigates the capabilities of ChatGPT within mechanical engineering education, particularly its performance on the Fundamentals of Engineering, Mechanical Engineering and Undergraduate Exams. This research is instrumental in understanding the potential impacts and limitations of AI tools like ChatGPT in engineering education, especially concerning academic integrity. The study's findings provide insights into ChatGPT's proficiency in answering complex engineering questions, while also showing the ethical considerations of using such AI tools in academic assessments. By assessing ChatGPT's

performance and its implications for academic integrity, [17] contribute significantly to the discourse on the responsible integration of AI in educational settings.

Together, these studies illuminate the ethical challenges and academic integrity issues arising from AI integration in education. They emphasize the need for balanced and responsible implementation of AI tools, highlighting the role of educators and institutions in navigating these challenges. The research by [11] and [17] serves as a critical reminder of the importance of ethical considerations and academic integrity in the rapidly evolving landscape of AI applications in educational contexts.

Research Implications

The study by [11] indicates a pressing need for further research into AI ethics education, particularly how it is currently addressed within engineering programs and its effectiveness in preparing students to tackle ethical dilemmas presented by AI. This research should explore pedagogical approaches that integrate ethical reasoning and sociotechnical considerations into the core curriculum. Similarly, the work of [17] emphasizes the importance of understanding the potential impacts of AI tools like ChatGPT on assessment integrity in engineering education, suggesting a need for more comprehensive studies to assess AI's accuracy in academic evaluations and its implications for maintaining academic integrity.

Practice Implications

In terms of practice, the findings from [11] suggest that engineering educators should incorporate comprehensive AI ethics training into their curricula to ensure that students are able to identify and address the broader ethical implications of AI technologies. [17] also imply that educators and institutions should be cognizant of the ethical challenges and academic integrity issues that arise from the use of AI in academic settings. It is crucial for educators to implement AI tools responsibly and to consider the development of AI-resistant examination questions to maintain the credibility and integrity of engineering assessments.

Theme 3: AI's Role in Personalized Learning and Assessment

AI's role in personalizing the educational experience and revolutionizing assessment methods is a rapidly evolving area of interest in the realm of engineering education. This theme highlights AI's capacity for tailoring educational content and delivery to individual student needs, learning styles, and performance levels, facilitated by its ability to analyze extensive data on student performance and learning habits. Such adaptive learning systems are pivotal in maximizing student engagement and optimizing learning outcomes.

In terms of assessment, AI is transforming traditional evaluation methods by automating the creation and grading of assessments, including intelligent assessment systems that can generate diverse question types, provide instant grading, and offer detailed feedback [3]. This enhances the objectivity and efficiency of academic evaluations. This theme also addresses AI's implications in maintaining the integrity and fairness of assessments, exploring how AI can be used to detect academic dishonesty and ensure equitable evaluation processes. Papers in this theme, such as those by [3], [8], [10],[18] and others, provide insights into innovative AI-driven assessment strategies supporting comprehensive student understanding evaluation.

Exemplar Studies

In addressing the theme "AI's Role in Personalized Learning and Assessment," two notable studies offer substantial insights. The first study, conducted by [8], presents a unique perspective on introducing machine learning concepts to first-year undergraduate engineering students. This exploratory study is significant for its use of authentic and active learning tools, including a public Google site repository and a course project. The methodology adopted by [8] is innovative, as it engages students in an introductory algorithms and MATLAB programming course. The study's findings indicate an increased recognition of the importance and usefulness of machine learning among students, though it also reveals perceived challenges in grasping these concepts. The approach employed by [8] highlights the transformative role AI technologies, particularly machine learning, can play in personalizing educational content and tailoring it to individual student needs and learning styles.

The second pivotal study in this theme is conducted by [10], which undertakes an empirical investigation into ChatGPT's capabilities in providing feedback on undergraduate students' argumentation. This retrospective analysis, which involved sophomores majoring in education at a university in Southern China, measures the precision and recall rates of ChatGPT's feedback compared to that provided by human experts. [10] study is crucial in understanding how AI can revolutionize assessment methods. The research demonstrates ChatGPT's potential in automating assessments and providing real-time, customized feedback to optimize learning outcomes. However, it also underscores the challenges associated with ensuring the accuracy and reliability of AI-generated feedback.

Both studies, by [8] and [10], collectively elucidate the significant role AI can play in facilitating personalized learning experiences and reshaping traditional assessment methodologies. These contributions are instrumental in highlighting how AI technologies can be optimized to cater to diverse learning styles and needs, thereby revolutionizing the educational landscape.

Research Implications

The research by [8] and [10] highlights the transformative potential of AI in personalizing learning and assessment. There is an essential need for further exploration into the efficacy of AI in providing customized educational experiences and its role in reshaping traditional evaluation methods. Future studies should assess how AI-driven feedback mechanisms can be optimized for individual learning needs and styles, and how AI can be integrated into various educational environments to enhance student engagement and learning outcomes.

Practice Implications

For practitioners, the work of [8] and [10] suggests leveraging AI to create more personalized and efficient learning experiences. Educators are encouraged to incorporate AI tools in teaching and assessment, ensuring these technologies serve as aids to enhance traditional methods. The implication is clear: educators must remain informed about the latest AI developments and ethical considerations, ensuring AI tools are used responsibly within educational settings. It is paramount for educators to ensure that AI applications do not compromise the quality of education and are employed to augment human teaching.

Theme 4: Challenges and Limitations of AI in Education

This theme delves into the challenges and limitations inherent in the use of AI in educational contexts, with a specific focus on engineering and technology fields. It critically examines concerns such as AI's ability to understand and interpret complex engineering concepts and its limitations in handling nuanced academic content. Key papers like those by [9] [18-20] and others, explore the potential for AI-generated misinformation, underscoring the importance of human oversight and validation in educational settings where AI tools are used. The theme highlights instances where AI struggles to grasp advanced engineering topics, emphasizing that AI should be viewed as a complementary tool, not a replacement for traditional educational methods. The risks of overreliance on AI, such as diminishing critical thinking and problem-solving skills among students, are also discussed. The papers under this theme offer insights into navigating the integration of AI in education while mitigating potential drawbacks.

Exemplar studies

For the theme "Challenges and Limitations of AI in Education," the studies by [18] and [19] provide essential insights into the practical obstacles and constraints of implementing AI in educational contexts, especially in engineering education. [18] offers a fascinating exploration of the integration of deep learning and computer vision into the curriculum for multidisciplinary engineering students. This educational intervention, set within a robotics design and applications course, demonstrates both the potential and the challenges of incorporating AI into engineering education. Avanzato's study utilized transfer learning to facilitate the use of complex algorithms by students, reducing the need for extensive databases and specialized hardware. However, the study also brings to light the difficulties students face in grasping advanced AI concepts, highlighting the importance of real world, project-based learning in overcoming these challenges. This study underscores the need for a balanced approach to AI education, where AI tools complement traditional teaching methods rather than replace them.

The study [19] delves into the application of machine learning models in chemical engineering, providing a comprehensive analysis of their strengths, weaknesses, opportunities, and threats. Their research critically examines the limitations inherent in AI's use in educational settings, such as the black-box nature of models and the risks of overfitting. The study also addresses challenges related to data quality and quantity, emphasizing the importance of data curation in the effective application of AI. [19] insights are crucial in highlighting the limitations of AI in understanding complex and nuanced academic content, pointing to the necessity of human oversight and validation in educational settings where AI tools are used.

Together, these studies from [18] and [19] shed light on the critical need for a nuanced approach to AI integration in education. They highlight the importance of addressing the challenges and limitations of AI, ensuring that its use in educational settings is both effective and responsible. These studies emphasize the significance of maintaining a balance between AI assistance and the development of critical thinking and problem-solving skills in students.

Research Implications

The studies by [18] and [19] underscore the importance of continued research into the practical limitations and challenges of using AI in educational contexts. Future research should focus on developing strategies to enhance AI's interpretability, especially in complex subject areas like engineering, and to mitigate misinformation generated by AI. There is also a need for studies that

examine the efficacy of AI in understanding nuanced academic content and that investigate how to balance AI tools with traditional educational methods to maintain the development of critical thinking and problem-solving skills in students.

Practice Implications

The practice implications drawn from the studies by [18] and [19] highlight that educators need to be mindful of AI's limitations in educational settings. [18] project-based learning approach for deep learning in multidisciplinary engineering underscores the need for educators to develop curricula that integrate AI tools in a manner that enhances human teaching. This includes using AI for tasks well-suited to its capabilities, such as data analysis and pattern recognition, while reserving more complex, subjective, or nuanced tasks for human instructors. Moreover, [19] points out the importance of understanding the potential for AI to inadvertently promote misinformation or biases. Educators should guide the selection and application of AI tools in educational settings, ensuring accuracy and relevance. The studies advocate for the teaching of both the potential and the limitations of AI, preparing students to use these tools effectively and ethically. This approach could help bridge the gap between technical AI knowledge and its application in specific fields like engineering.

Theme 5: Future of AI in Engineering Education

The future of AI in engineering education is a dynamic and rapidly evolving theme, focusing on the long-term implications, advancements, and transformative potential of AI technologies in reshaping educational landscapes, especially in engineering and related disciplines. Papers such as those by [7], [21-22] and others, provide insights into the evolving role of AI, speculating on future developments, potential innovations, and how AI will continue to influence teaching methods, learning experiences, and educational outcomes. This theme encompasses a forward-looking perspective on AI, contemplating how ongoing technological advancements will further personalize learning experiences, integrate into curriculum design, and facilitate experiential and immersive learning. Discussions also cover the continuous adaptation in educational practices required to keep pace with technological advancements and the anticipated challenges and ethical considerations of rapid AI evolution in education.

Exemplar Studies

Addressing the theme "Future of AI in Engineering Education," the studies by [7] and [23] provide forward-thinking insights into the evolving role and potential of AI technologies in reshaping the educational landscape for engineering and related disciplines. [7] offers an in-depth look at the prospective developments and advancements of AI in engineering education. The study speculates on how continuous technological progression will necessitate changes in educational practices, with AI playing a vital role in these transformations. Qadir's research is significant for its exploration of potential innovations in AI technologies and how these advancements might influence teaching methodologies, learning experiences, and educational outcomes in engineering. The study emphasizes the need for ongoing adaptation in educational practices to keep pace with rapid AI evolution, highlighting the challenges and opportunities this presents.

The study [23] conducted a comprehensive analysis of engineering and technology education in university studies, focusing specifically on a case study in Andalusia, Spain. Their research evaluates the alignment of engineering programs with future industry needs, particularly in the realm of intelligent systems like AI, IoT, and smart grids. Espinosa et al.'s study is crucial for

understanding how educational institutions can adapt their curricula to meet the demands of the evolving industrial landscape. The research underscores the importance of continuous curriculum improvement and faculty training to ensure that engineering education remains relevant and responsive to industry trends.

Both studies, by [7] and [23], collectively highlight the dynamic and rapidly evolving nature of AI in engineering education. They point to a future where AI not only enhances educational methodologies but also challenges traditional pedagogical approaches, advocating for curricula that are adaptive, forward-looking, and responsive to technological advancements. These studies serve as a guide for educators, policymakers, and curriculum designers, ensuring that future engineers are well-prepared to navigate and contribute to a technology-driven professional landscape.

Practice Implications

The study by [7] suggests that educators and institutions must prepare for the integration of AI into educational practices proactively. This includes developing curricula that incorporate AI tools to augment learning experiences while ensuring that these technologies are used ethically and responsibly. As AI becomes more pervasive, educators should adapt their teaching methods to leverage AI's capabilities, and institutions should foster an environment conducive to innovation and experimentation with AI in education. [23] reinforce this perspective, emphasizing the importance of continuous improvement and adaptation of teaching content to meet future demands. They highlight the need for engineering education to remain agile, flexible, and resilient to cater to industrial and social needs, which involves aligning educational programs with the evolving requirements of intelligent systems and related technologies.

Research Implications

From a research standpoint, the findings from [7] underscore the necessity for continuous exploration into AI's capabilities and limitations in the context of engineering education. Future studies should focus on developing and testing more sophisticated AI tools for educational purposes, examining their potential to enhance learning experiences, and integrating AI into curriculum design and delivery effectively. There is also a need for research on preparing educators and students for a future where AI plays a significant role in education, including the development of new pedagogical strategies and the necessity for ongoing professional development. Similarly, the work of [23] calls for research that examines the alignment of engineering programs with future industry needs, especially in intelligent systems. This research should investigate the presence of subjects related to intelligent systems in various engineering disciplines and the correlation with future market demands, advocating for continuous curriculum improvement and faculty training to ensure that engineering education remains relevant and responsive to industry trends.

Discussion

The systematic literature review (SLR) on generative artificial intelligence (AI) in undergraduate engineering education reveals a multifaceted landscape, characterized by rapid technological advancements and significant pedagogical shifts. This review, synthesizing diverse studies, has uncovered various themes that shape the current and future trajectories of AI in engineering education.

***Integration of AI in Engineering Education*:** The integration of AI in engineering education, particularly through tools like ChatGPT, marks a paradigm shift in educational methodologies. Studies like those by [3] and [5] highlight AI's role in enhancing problem-solving skills and supporting complex concept teaching. The potential of AI to bridge skill gaps and promote interdisciplinary learning aligns with the demands of the Fourth Industrial Revolution, necessitating a reimagined pedagogical approach that harmonizes with AI advancements [1-2]

***Ethical and Integrity Considerations*:** Ethical and academic integrity considerations emerge as critical factors in the adoption of AI in educational settings [11] [17]. The challenges of ensuring data privacy, mitigating AI biases, and preserving academic honesty underscore the need for a balanced and ethical integration of AI tools in education.

***Personalized Learning and Assessment*:** AI's capability to personalize education and revolutionize assessment methods, as evidenced in studies by [8] and [10], demonstrates its transformative impact on engineering education. This personalization promises more targeted and effective learning experiences, though it also brings forth the need for continuous adaptation in teaching methods and curricula.

***Challenges and Limitations of AI*:** Despite its numerous advantages, AI's application in education is not devoid of challenges. Limitations in understanding complex engineering topics [9][19] and risks of misinformation necessitate a cautious and complementary use of AI tools in education, ensuring that they enhance rather than replace human expertise.

***The Future of AI in Engineering Education*:** Looking ahead, the future of AI in engineering education appears promising yet demands ongoing adaptation. Studies like those by [7] and [23] suggest that continuous technological advancement will necessitate evolving educational practices, with AI playing a vital role in shaping these changes.

Conclusion

In this systematic literature review (SLR), we have explored the burgeoning influence of generative Artificial Intelligence (AI) in undergraduate engineering education, charting the current landscape, discerning trends, and extrapolating future directions. The study embarked on a comprehensive search across seven academic databases, employing five targeted search terms to amass a diverse collection of scholarly articles. Through a rigorous screening process, we initially retrieved 554 articles, which, after a detailed review and adherence to stringent exclusion criteria, culminated in a focused analysis of 24 seminal works. These articles, distilled from a vast initial corpus, illuminate the intricate tapestry of generative AI's application and its pedagogical implications within the engineering domain.

Our investigation has unveiled five pivotal themes that encapsulate the core findings of our review: the integration of AI in engineering education, the ethical and academic integrity considerations it invokes, its role in personalizing learning experiences and assessments, the challenges, and limitations inherent in its educational application, and the prospective future of AI within this field. These themes not only provide a structured understanding of the subject matter but also highlight the multifaceted impact of generative AI on pedagogical strategies, curriculum development, and the broader educational ecosystem.

By delving into the nuances of these themes, this study not only enhances the academic discourse surrounding generative AI in engineering education but also offers actionable insights for educators, policymakers, and curriculum developers. The aim is to foster an environment where future engineers are not only proficient in their traditional disciplines but are also adept at leveraging the expansive capabilities of AI. Through this comprehensive analysis, we contribute to shaping a future where engineering education is at the forefront of technological innovation, ethically grounded, and aligned with the evolving demands of the Fourth Industrial Revolution.

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Appendix: Articles categorized based on the five themes

#	Theme	References
1	AI Integration in Engineering and Technology Education:	Zawacki-Richter, O., Marín, V.I., Bond, M., et al. (2019). Systematic review of research on artificial intelligence applications in higher education – where are the educators? International Journal of Educational Technology in Higher Education, 16, 39. https://doi.org/10.1186/s41239-019-0171-0 Nikolic, S., Daniel, S., Haque, R., Belkina, M., Hassan, G. M., Grundy, S., Lyden, S., Neal, P., & Sandison, C. (2023). ChatGPT versus engineering education assessment: a multidisciplinary and multi-institutional benchmarking and analysis of this generative artificial intelligence tool to investigate assessment integrity. European Journal of Engineering Education, 48(4), 559-614. DOI: 10.1080/03043797.2023.2213169 Tsai, M.-L., Ong, C. W., & Chen, C.-L. (2023). Exploring the use of large language models (LLMs) in chemical engineering education: Building core course problem models with Chat-GPT. Education for Chemical Engineers, 44, 71-95. ISSN 1749-7728. https://doi.org/10.1016/j.ece.2023.05.001. Ünlütabak, B., Canbek Ozdil, Z.C., & Cirit, E.S. (2023). Exploring the Use of ChatGPT as a Learning and Teaching Tool in Material Science and Nanotechnology Engineering Education. ChemRxiv. Cambridge: Cambridge Open Engage. This content is a preprint and has not been peer-reviewed.

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2	Ethical and Academic Integrity Considerations:	Joshi, I., Budhiraja, R., Tanna, P. D., Jain, L., Deshpande, M., Srivastava, A., Rallapalli, S., Akolekar, H. D., Challa, J. S., & Kumar, D. (2023). "With Great Power Comes Great Responsibility!": Student and Instructor Perspectives on the influence of LLMs on Undergraduate Engineering Education. arXiv preprint arXiv:2309.10694. Orchard, A., & Radke, D. (2023). An Analysis of Engineering Students' Responses to an AI Ethics Scenario. Frenkel, M., & Emara, H. (2023). ChatGPT & Mechanical Engineering: Examining performance on the FE Mechanical Engineering and Undergraduate Exams. arXiv preprint arXiv:2309.15866. Braude, E. (2023). Value-Added Grading of AI-Assisted Papers. In International Conference on Computer Science and Education in Computer Science (pp. 399-406). Cham: Springer Nature Switzerland. De Silva, D., Mills, N., El-Ayoubi, M., Manic, M., & Alahakoon, D. (2023). ChatGPT and Generative AI Guidelines for Addressing Academic Integrity and Augmenting Pre-Existing Chatbots. In 2023 IEEE International Conference on Industrial Technology (ICIT) (pp. 1-6). IEEE. Pursnani, V., Sermet, Y., Kurt, M., & Demir, I. (2023). Performance of ChatGPT on the US fundamentals of engineering exam: Comprehensive assessment of proficiency and potential implications for professional environmental engineering practice. Computers and Education: Artificial Intelligence, 5, 100183.
3	AI's Role in Personalized Learning and Assessment	Avanzato, R. L. (2023). Deep Learning Projects for Multidisciplinary Engineering Design Students. In 2023 ASEE Annual Conference & Exposition. Wang, L., Chen, X., Wang, C., Xu, L., Shadiev, R., & Li, Y. (2024). ChatGPT's capabilities in providing feedback on undergraduate

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4	Challenges and Limitations of AI in Education	Dobbelaere, M. R., Plehiers, P. P., Van de Vijver, R., Stevens, C. V., & Van Geem, K. M. (2023). Machine learning in chemical engineering: strengths, weaknesses, opportunities, and threats. Engineering, 7(9), 1201-1211. Dwivedi, Y. K., Kshetri, N., Hughes, L., Slade, E. L., Jeyaraj, A., Kar, A. K., ... & Wright, R. (2023). "So what if ChatGPT wrote it?" Multidisciplinary perspectives on opportunities, challenges and implications of generative conversational AI for research, practice and policy. International Journal of Information Management, 71, 102642. Bahroun, Z., Anane, C., Ahmed, V., & Zacca, A. (2023). Transforming education: A comprehensive review of generative artificial intelligence in educational settings through bibliometric and content analysis. Sustainability, 15(17), 12983.
5	Future of AI in Engineering Education	Qadir, J. (2023). "Engineering Education in the Era of ChatGPT: Promise and Pitfalls of Generative AI for Education," 2023 IEEE Global Engineering Education Conference (EDUCON), Kuwait, Kuwait, pp. 1-9. Lawan, A. A., Muhammad, B. R., Tahir, A. M., Yarima, K. I., Zakari, A., Abdullahi II, A. H., ... & Lawan, S. (2023). Modified flipped learning as an approach to mitigate the adverse effects of generative artificial intelligence on education. Educ J, 12(4), 136-143. Sriwastwa, A., Ravi, P., Emmert, A., Chokshi, S., Kondor, S., Dhal, K., ... & Gupta, R. (2023). Generative AI for medical 3D printing: a comparison of ChatGPT outputs to reference standard education. 3D Printing in Medicine, 9(1), 21. Ibrahim, H., Liu, F., Asim, R., Battu, B., Benabderrahmane, S., Alhafni, B., ... & Zaki, Y. (2023). Perception, performance, and detectability of conversational artificial intelligence across 32 university courses. Scientific Reports, 13(1), 12187.