Path to Personalization: A Systematic Review of GenAI in Engineering Education

Rubaina Khan
University of Toronto
Toronto, Ontario, Canada

Sreyoshi Bhaduri*
Amazon
Arlington, Virginia, USA

Tammy Mackenzie
The Aula Fellowship
Mirabel, Quebec, Canada

Animesh Paul
University of Georgia
Athens, Georgia, USA

Sankalp KJ
University of South Carolina
Columbia, South Carolina, USA

Indrani Sen
Georgia Tech
Seattle, Washington, USA

Abstract

This systematic review paper provides a comprehensive synthesis across 162 articles on Generative Artificial Intelligence (GenAI) in engineering education (EE), making two specific contributions to advance research in the space. First, we develop a taxonomy that categorizes the current research landscape, identifying key areas such as Coding or Writing Assistance, Design Methodology, and Personalization. Second, we highlight significant gaps and opportunities, such as lack of customer-centricity and need for increased transparency in future research, paving the way for increased personalization in GenAI-augmented engineering education. There are indications of widening lines of enquiry, for example into human-AI collaborations and multidisciplinary learning. We conclude that there are opportunities to enrich engineering epistemology and competencies with the use of GenAI tools for educators and students, as well as a need for further research into best and novel practices. Our discussion serves as a roadmap for researchers and educators, guiding the development of GenAI applications that will continue to transform the engineering education landscape, in classrooms and the workforce.

CCS Concepts

• **Social and professional topics → Computational science and engineering education**; *Software engineering education*; *CS1*; • **General and reference → Surveys and overviews**; • **Applied computing → Computer-assisted instruction**.

Keywords

Engineering Education, AI4Edu, AI Personalization, Gen AI in Education

1 Introduction

The swift evolution of Artificial Intelligence (AI) technologies, notably Generative AI (GenAI) and Large Language Models (LLMs), unlocks unprecedented opportunities in education. While existing reviews have successfully and comprehensively surveyed the opportunities of and challenges for GenAI in higher education (e.g., [37], [40], [56], [114], [153]), a significant knowledge gap still remains in engineering education. Engineering education (EE) is a specialized field of study that focuses broadly on the teaching and learning of and among engineers ([172], [120], [178]). This paper aims to address this gap by providing a systematic review of recent studies in that investigate the applications, assessments, and future implications of GenAI in EE. We conducted a review, emphasizing rigorous inclusion criteria across five prominent databases: ERIC, PsycINFO, CINAHL, Web of Science, and Engineering Village. Findings indicate a diverse range of GenAI applications being used and of consideration in EE, including coding assistance, design, methodology, writing assistance, personalized learning, along with some position and survey papers on the topic. Broadly, this paper contributes to the ongoing conversation on GenAI's potential for transforming educational practices. Specifically, we believe that the path to personalization in the teaching and learning of and among engineers will need to be constantly reinforced by engaging intersectional scholarship from research, education, industry, and policy. Particularly, our findings underscore the importance of guiding the design processes of GenAI personalized learning drawing heavily from research within the broader science of EE, learning sciences, and workforce development.

2 Background

In the past few decades, the post-secondary education landscape has evolved dramatically through massification initiatives to respond to growing societal demands on engineers and to increase participation [7]. As such, post-secondary institutions are dealing with issues like resource constraints around designing curriculum and evaluation strategies [9][32][65] [179], ensuring equitable and inclusive access to learning [57] [42][116], and providing flexible pathways for fresh graduates [136][130][33]. Significantly, given public financing cuts on education around the world [129], and the repurcussions from the recent pandemic [145][86], institutions are finding ways to innovate. The use of machine learning and natural language processing in engineering education research and classrooms is not new [17] [79][18][19]. The widespread potential of GenAI in post-secondary education provides opportunity for major innovations in teaching and learning. Researchers in engineering education have found that GenAI can be used to improve administrative tasks and backlogs [95], to facilitate resource allocation [27], and to enable higher engagement with students through personalized mentoring [147]. These promising use-cases have led to large-scale investments, disrupting traditional ways of learning and tutoring [110]. However, GenAI has raised concerns among educators and institutions, primarily dealing with plagiarism [76], renegotiating the role of instructors [6], and ethical concerns, for example around using student data [34]. These tensions have led

*Work does not relate to position at Amazon.

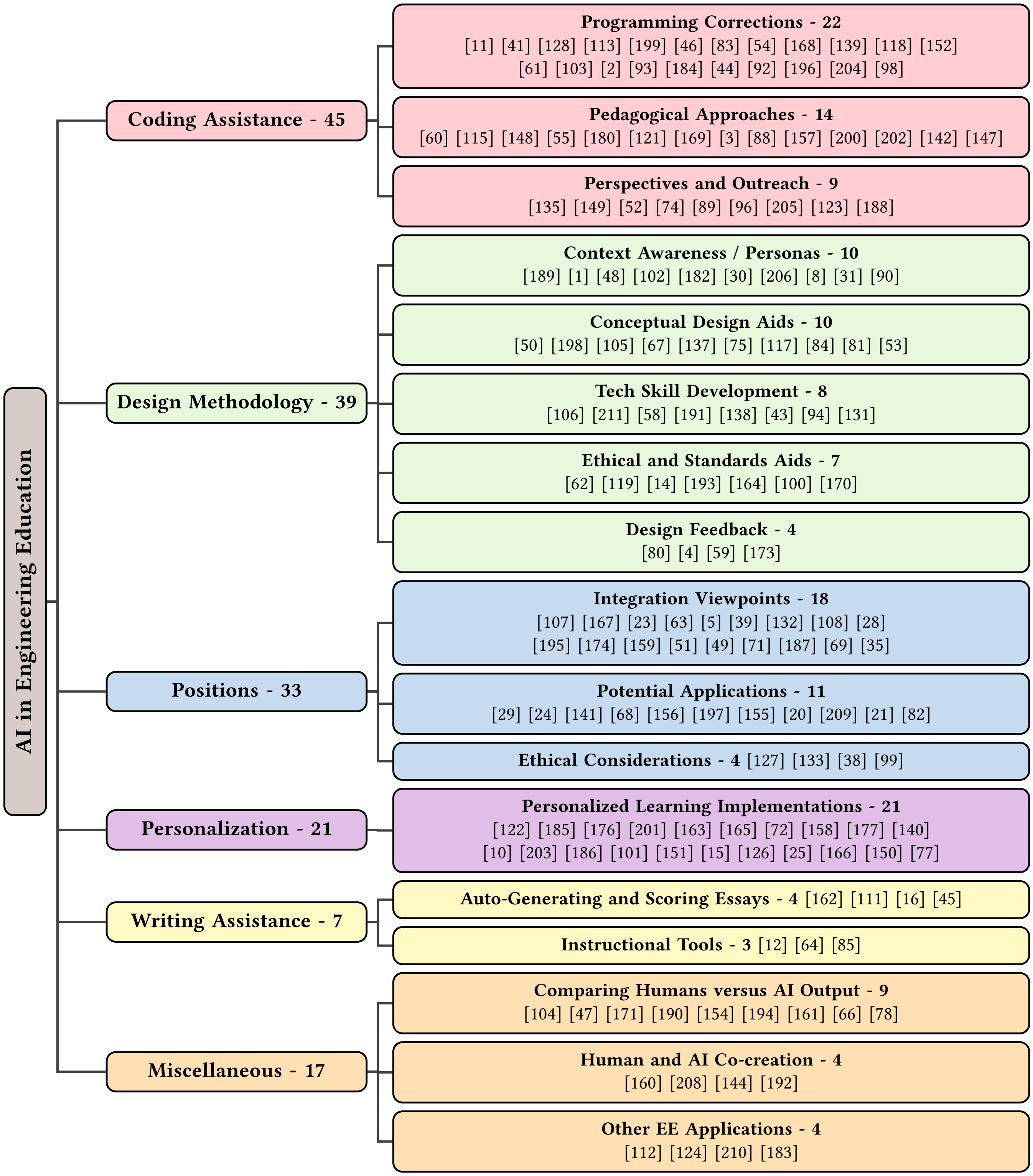

Figure 1: This taxonomy categorizes 162 papers describing the use of GenAI in Engineering Education (EE) into six broad objectives: Coding Assistance, Design Methodology, Positions, Personalization, Writing Assistance, and Miscellaneous

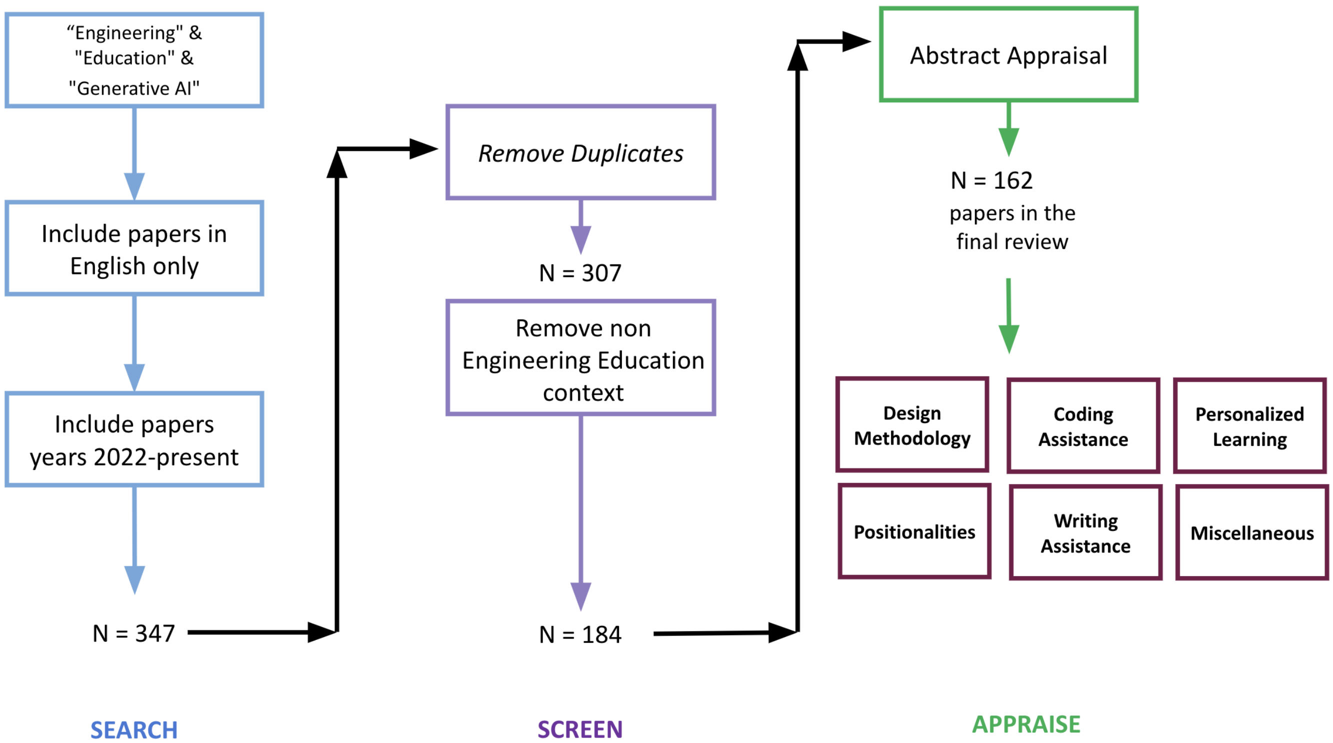

Figure 2: Visualization of the Search-Screen-Appraise method employed for inclusion and exclusion of research studies in this review

researchers to beseech developers to create solutions that speak to systemic barriers [146], employ transparent methodologies [36], and co-design with educators [91]. In EE, the issues discussed above are prevalent. EE institutes must ensure that their graduates have the technical skills to develop products and processes embedded in complex systems that work seamlessly [109]. These systems must be developed with sustainable mindsets and use ethical design methodologies [26]. However, such sophisticated education expectations are not always adapted to large classroom sizes and budget constraints. Therefore, GenAI is promising for engaging learners from various backgrounds with dynamic, personalized, and effective tools [73]. Given these potential advantages, further research is needed to explore the performance of GenAI tools in teaching epistemic content [207], within the context of the professional skills needed in industry [175], and to engage in the critical thinking required to solve "wicked" problems [134]. Lastly, EE training needs to show the implication of engineering work in a society [125] that requires development of human values [97], empathy development [181], lifelong learning [87] and taking on responsibility for sustaining our planet [13].

3 Methodology

Our review highlights the range of applications, key pedagogical approaches, and elucidates motivations for GenAI integration in engineering curricula and classrooms. The methodology uses the Search-Screen-Appraise approach [22] as visualized in Figure2, to set strict inclusion criteria and engage in a precise study selection process. Initial searches were conducted across prominent databases: ERIC, PsycINFO, CINAHL, Web of Science, and Engineering Village, chosen for their comprehensive coverage of education and engineering literature. Keywords including "Engineering," "Education," and "GenAI" were used in each database to ensure relevance and comprehensiveness. A systematic review tool (Rayyan [143]) was used first, to identify and exclude 40 duplicates from a total of 347 initial search results, resulting in 307 unique records for further evaluation. Abstracts and titles were further screened to identify papers specifically relevant to EE and discussing GenAI. Missing abstracts or other information was updated through supplementary searches and integrated into the review process to ensure completeness and accuracy. Results and, in some cases, full texts were consulted when necessary to establish inclusion. The team then collectively classified papers by assigning labels within Rayyan, breaking down the papers included into six broad categories and subsequently, sub-categories with at least two researchers agreeing on the category assigned. Though there were some studies of GenAI in education before the release of ChatGPT to the public, we found only 1 that specifically addressed GenAI for engineering studies, and others were for technologies that were replaced by users when GPT was launched to the public. Consequently, the earliest papers in this review are from 2022. Also excluded are non-English publications, conference proceedings, non-engineering, non-education, and non-GenAI studies. Our process resulted in the inclusion of 162 papers in the final review.

4 Findings

This review of 162 articles on AI in Engineering Education reveals a diverse and rapidly evolving landscape (see Figure 1). A majority of the papers, i.e. 45, focused on Coding Assistance, with a significant emphasis on programming or code correction while a notable subset explored pedagogical approaches to teaching coding or software engineering. Design Methodology was the second prominent theme, with 39 papers addressing various aspects such as Context Awareness, Conceptual Design Aids, Technological Skill Development, Design Feedback, and Ethical Standards. Additionally, the review uncovered a substantial number, i.e., 33 Position papers offering perspectives on the integration of AI in engineering education, alongside smaller clusters of research specific to Personalization (21), Writing Assistance (7), and other Miscellaneous topics in the domain (17), collectively shedding light on the multifaceted potential of AI in enhancing engineering education.

4.1 Coding Assistance

Unsurprisingly, our review uncovered a significant concentration of research on coding assistance based applications of GenAI in engineering education. We found three broad sub-categories among these 45 papers focussed on Coding Assistance. Half of the papers were focused on GenAI based programming correction, with authors focused on the degree of correctness of the AI solutions (e.g., [11], [128], [199]), creation of customized and ready to use programming exercises(e.g., [184]) or even attempting to distinguish between human-generated or AI code (e.g., [92, 93, 98]) Next, a handful of authors were focused more on bringing changes to pedagogical approaches in the age of Generative AI, focusing their papers on strategies to enhance teaching and assessing coding or prompting among learners. Examples from this sub-group include one designing a system to help students learn how to write effective prompts ([55]) and a Human Centered AI approach to understand how post-primary students in Ireland engage with GAI tools ([180]). Finally, the third sub-group of papers were ideologically focused with little or no empirical results, reporting on surveys, perspectives and positions or report outs from outreach workshops (e.g., [188], [148], [89]). While these research directions hold promise, our review revealed a predominant focus on evaluating code accuracy, with a majority of paper abstracts reporting on the successes and limitations of different AI applications in augmenting coding practices, rather than focusing on the necessary pedagogical approaches needed to augment classrooms in preparation for such disruptive technology. Although this preliminary surge of emphasis on technical proficiency is anticipated, we hope that future research will expand its scope to investigate the importance of teaching students to responsibly leverage AI in coding, considering crucial aspects like fairness, accountability, and transparency. As the field continues to evolve, it is essential to prioritize not only technical competence but also ethical awareness and responsible AI integration in engineering education, ensuring that future engineers are equipped to harness AI's potential while mitigating its risks.

4.2 Design Methodology

39 papers included in this review are categorized as Design Methodology papers. These papers discuss the uses of GenAI tools to teach broad design thinking, human-computer interaction, and engineering design. The papers elaborate the use of GenAI tools at various stages of the design process, including exploring alternative designs, understanding design contexts, and expanding awareness of regulatory design codes and regulations. For example, [189] used chatbots to generate personas to mimic real people and potential users of the designs to be created by students. Few papers presented case studies on LLMs can be leveraged for complex queries, interdisciplinary approaches to engineering design, and context awareness. Some studies showed how GenAI can be used to expedite design thinking, like in generating conceptual designs in mechanical engineering [81], making ethical choices during prototyping in time-sensitive situations such as hackathons [164], and learning disciplinary skills needed for design projects through personalized learning [138]. Lastly, a handful of papers explore how GenAI tools can give timely, relevant, and epistemic feedback during design. One example is the use of ChatGPT to analyze progress reports, instrumental to team collaborations, by recommending readability improvements and clarifying complex ideas [137].

4.3 Positions

Our review found 33 position papers revealing diverse viewpoints on its integration, ethical considerations, and potential applications of GenAI in EE. Specifically, these papers are where authors argue their stance on or against the use of GenAI in EE, highlighting critical discussions often overlooked by the broader education or AI community. While one paper [174] advocated for enhancing GenAI in Data Science through prompt engineering, another [159] emphasized understanding AI's influence on student projects in software engineering. Notable other contributions include papers discussing mixed student experiences with ChatGPT in aviation education [197], specifically addressing trust in AI for programming tasks [156], and pointing out technical limitations of GPT models in educational distribution systems [21]. Non-empirical studies included in these review examined the promise and ethical considerations of GenAI [99] and advocated for a balance between benefits and risks. Others [24] discuss the transformative potential of AI in education and its ethical challenges, or reflected on conversational AI's broad impacts on research and policy, stressing responsible use [63], highlighting the need for more assessments of GenAI in engineering education [133], proposing future scenarios for AI in software development, emphasizing productivity and ethical concerns [167], and suggesting a co-evolutionary approach to GenAI in human creativity [20]. These positionality related studies collectively underscore the transformative potential of GenAI across different engineering disciplines, advocating for responsible integration, addressing quality, privacy, and equitable access, and highlight the need for ongoing dialogue within the AI community to ensure a balanced and ethically grounded approach.

4.4 Personalization

21 of the reviewed studies have specifically investigated GenAI's potential for personalized learning experiences. Most studies explore AI's potential for personalization and adaptive learning, proposing frameworks and systems to tailor educational experiences to individual needs (e.g., [122, 158, 165]. AI-enhanced assessment and

feedback is another prominent area, with researchers investigating the use of large language models for answering assessment questions and providing formative feedback ([151, 177, 203]. The integration of AI into various educational tools and platforms, including chatbots, virtual reality labs, and career guidance systems, is also a focus (e.g., [10, 72, 186]). Some studies examine how AI tools are changing students' information-seeking and learning behaviors ([15, 101]. Ethical considerations and challenges, such as ensuring equitable access to AI technologies and addressing potential misuse, are recurring concerns discussed across papers in this category (e.g., [15, 140, 176]). Finally, many researchers highlight the need for future work, including long-term studies on learning outcomes, addressing current AI limitations, and developing best practices for AI integration in education (e.g.,[140, 151, 177]). This body of research thus demonstrates both the significant potential of AI to transform education with an emphasis on personalization while also highlighting the need for careful implementation and ongoing research to carefully address challenges and ethical concerns.

4.5 Writing Assistance

7 studies explored the use of ChatGPT for generating or scoring text-based content in EE. Similar to the papers under Coding Assistance, although significantly fewer, the papers related to Writing Assistance followed largely from overall industry trends around text generation, essay writing, and consequent scoring. These papers are sub-classified into 4 papers related more specifically to auto-generation and scoring of essays specific to a prompt versus using generative capabilities towards developing instructional tools. Notably, researchers developed an effective three-step prompting process (write, curate, verify or WCV) for teachers to generate quality scenarios efficiently [12]. Some studies ([46] [85]) also provide guidelines for implementing the WCV approach in educational settings, demonstrating the potential of GenAI to enhance teaching and learning experiences in higher education. In another study [64], students showed increased motivation, improved learning performance, and positive attitudes towards the AI-generated scenarios, aligning with findings on a similar study [16] related to AI-augmented learning.

4.6 Miscellaneous

A section of papers were grouped under the Miscellaneous label. More than half of these 17 papers were concerned with comparing human and AI outputs across domains. One example [190] compared the results of various LLM responses to mechanical engineering exam questions while another [161] performed a similar test on computer engineering exam questions. Most of these papers tended to find mixed results depending on the evaluation frameworks selected. This is to say, humans and AIs do not perform similarly on all metrics, and so in some cases, the LLM can be found to outperform humans, for example, in applying heuristics, while humans may beat the LLMs on math (e.g., [194], [154]). Authors across these papers recommend that educators think deeply about the critical choices on when to use these tools and also underline that the technology is changing very quickly. Other studies under the miscellaneous label emphasized connecting LLMs with engineering, but came from other non-engineering fields. We excluded most such studies if they didn't also apply to engineering. What remains are 3 case studies or experiments in human-ai co-creation. These papers have very small samples are indications of good reasons for human-ai collaborations, elaborating on things like efficiency in summarizing data and collaborations that fail. For example, in one interesting case, because human biases and AI biases both exist but don't necessarily match each other, the authors [160] demonstrate how co-creation requires building up mutual understanding, in a way very different from a usual relationship between an artist and their tools.

5 Discussion

From our findings, we see engineering educators found immediate relevancy of GenAI applications in scaffolding, the learning process through just-in-time feedback and epistemic guidance. These findings align with the premise for AI-enhanced personalized learning systems that feedback and guidance must be tailored for every student based on progress, learning preferences, demographics, and interests. However, for these tools to find mass relevance across engineering institutions, they must add just-in-time value to what educators need and aspire to have in their classrooms. Personalized learning systems can close the feedback loop between students and educators with meaningful outcomes. Still, there remain certain considerations that should be accounted for while paving the path to increased personalization in this space.

Path to Personalization is currently reactive to industry and lacks clear customer needs. Most of the applications elaborated in the papers reviewed were reactive to broader advancements in the GenAI space - for instance, productized automated code generation and error correction are broad industry focused applications, which educators were implementing in their classrooms. While these more reactive applications are expected - to avoid instances of the metaphorical GenAI "hammer" looking for a education use-case "nail", there is immense potential for engineering educators to lead clear definition of specific problems that students and educators face that can then be mapped to AI-based solutions. A customer-centric approach centering learners and teachers is a missed opportunity in the domain. For example, our review did not find research and applications of GenAI tools to address the holistic development of future or current engineers. There is an opportunity for GenAI tools to help educators understand, develop, and teach these necessary skill sets to future and current engineers. Through centring educators' voices and engaging learning scientists to characterize how 21st-century skills develop, the development of future GenAI tools will offer personalized pathways that are memorable, inclusive, and encouraging learning experiences.

Path to Personalization will need to be paved with increased transparency. Most GenAI systems perform best when given access to various student datasets such as student demographics, academic achievement history, self reflections, etc. There are related regulatory and ethical considerations related with these datasets that are often not considered in tandem with the fast pace of innovation of GenAI applications in EE. Clearer indications from academia and associated AI researchers of how student data was collected ethically and processed using transparent methods would allow applications to flourish among educators. Also related to the theme of transparency, very limited papers presented their pseudocode or prompts in describing their applications. In general, since GenAI outputs are non-deterministic, meaning that they can vary across iterations, the availability of prompts provides a semblance of attempts to reproduce results and transfer findings across settings. Broadly, authors in this domain must consider publishing not only their findings but also their GenAI prompts and architecture used to engineer the outcome.

Path to Personalization will require augmenting just-in-time educator and instructor training and resources to help democratize the use of GenAI across classrooms, especially as educators plan to infuse technology in design curriculum. As highlighted across many of the categories in our findings, educators found value in GenAI tools to give feedback and generate course materials related to technical skills development for engineering students. In particular, a large number of studies focussed on how GenAI tools may help with teaching various aspects of engineering design. This finding shows that engineering educators plan and enact various scaffolds to teach engineering design at various stages of the undergraduate journey. As such, there is an opportunity to enhance support, self-service, and ease of implementation of Gen AI tools to support faculty developing and assessing various competencies, such as within design courses. On a curriculum level, personalized learning systems may track and guide individual students to leverage their strengths as they start a new design experience and recommend curricular and supplementary materials to address their weaknesses.

Path to Personalization will need to emphasize value-driven design. Our review found that developers of the GenAI tools did not specify the values that motivated their design. This means we must first drive research efforts that tackle key issues in post-secondary education, such as well-being, inner development, and inclusion. These constructs are complex and difficult to characterize. As such, we can involve learning scientists in the development stages of GenAI tools to guide the design process using learning theories from evidence-based studies. Therefore, the outcomes of these tools must be evaluated with metrics centring critical and sociocultural approaches to learning [70] that would help us to know what benefits EE educators and students the most when using GenAI systems.

6 Closing Thoughts and Potential for Future Work

Our paper begins to unearth the gaps as well as the immense potential and possibilities of GenAI in EE. Future work in this field is vast and will be crucial. Successful future work will also be increasingly multi-disciplinary bringing in expertise across domains such as education policy, education research, learning sciences, and of course, AI and product research. One of the primary concerns for the broader field is to explore the ethical implications and overall impact of GenAI in the development of engineering identity, including addressing the repurcussions from the potential biases in AI-generated content and the apparent tech divide. Additionally, user experience research centered around teachers and learners will be needed to develop and test increasingly personalized GenAI-powered learning environments that adapt to individual students' needs and abilities. Further, as AI research continues to advance rapidly, researchers in this space can be more proactive in anticipating the integration of GenAI with other technologies like virtual and augmented reality to unlock new, learner-centered possibilities for immersive and interactive experiences.

For this review, future work will include expanding the corpus of included research and iterating to refine the taxonomy through ongoing research to ultimately provide a comprehensive framework for understanding the evolving landscape of GenAI in engineering education.

The path forward for the use of generative AI in education leads to personalization and intentional research will ensure that the path inclusively and effectively harnesses the full potential of emerging technologies to transform engineering education and equip the current and next generation of engineers for success.

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