Exploring the Role of Generative AI in Developing Durable Skills: An Exploratory Literature Review

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Abstract – The rapid advancement of Generative Artificial Intelligence (GenAI) presents both opportunities and challenges for engineering education, particularly in fostering durable skills such as critical thinking, problem-solving, creativity, communication, and collaboration. While AI-driven tools have the potential to transform educational methodologies, empirical evidence on their effectiveness in skill development remains limited. This exploratory literature review synthesizes existing research to examine GenAI's role in fostering durable skills in engineering education. The review evaluates key insights, challenges, and gaps in the adoption of AI-driven tools, highlighting ethical, pedagogical, and practical considerations. Findings reveal that while GenAI tools offer personalized learning, adaptive feedback, and interactive engagement, their widespread adoption is hindered by faculty resistance, lack of technical training, fairness concerns, and the absence of standardized evaluation frameworks.

By analyzing the current landscape, this review provides practical recommendations for integrating GenAI into engineering curricula, emphasizing the need for faculty development programs, interdisciplinary research collaborations, and ethical implementation frameworks. Additionally, it identifies critical research gaps, calling for longitudinal studies, AI literacy frameworks, and cross-disciplinary investigations to assess the long-term impact of GenAI on skill development. This review contributes to the ongoing dialogue on AI's role in engineering education, offering insights for educators, policymakers, and researchers. By ensuring a balanced approach that leverages GenAI's capabilities while safeguarding human-centric education, this review aims to inform policy, drive future research, and optimize GenAI's potential in preparing students for an AI-integrated world.

Introduction

In the rapidly evolving landscape of engineering education, developing durable skills such as critical thinking, problem-solving, creativity, communication, and collaboration has become increasingly essential. As industries and workplaces continue to adopt advanced technologies, particularly artificial intelligence (AI), the demand for professionals equipped with these skills has intensified [1]. Generative AI (GenAI) tools, which are transforming various sectors, offer the potential to revolutionize educational methodologies by fostering these critical skills among students. These tools, such as ChatGPT, can provide adaptive learning experiences, real-time feedback, and interactive problem-solving opportunities [2], [3].

While the integration of AI into educational environments promises to create more personalized, engaging, and effective learning experiences, its potential impact on durable skill development remains underexplored. Durable skills, also referred to as "soft skills," "professional skills," "21-century skills," or "essential skills", are indispensable in preparing students for a future workforce shaped by technological advancements and Industry 5.0, where human-centric collaboration with intelligent systems is key [4]. However, educators face significant challenges in adopting these technologies, including technical limitations, faculty

resistance due to lack of familiarity, and ethical concerns related to data privacy, bias and algorithmic decision-making [5], [6].

Despite its transformative potential, GenAI raises concerns regarding its long-term efficacy in enhancing durable skills and the risks of over-reliance. Some educators have expressed concerns about whether these tools might inadvertently undermine essential human competencies, such as creativity and interpersonal communication [1]. There is also a pressing need for empirical studies that evaluate GenAI's effectiveness in fostering these skills across diverse educational contexts [7], [8].

This study conducts an exploratory literature review to examine the role of GenAI tools in fostering durable skills in engineering education. Given the nascent and rapidly evolving nature of GenAI in education, this review aims to synthesize existing research, identify key insights and challenges, and propose directions for future study. This review seeks to address the following research questions:

- How are GenAI tools currently used to support the development of durable skills in engineering education?
- What challenges and ethical considerations arise from their adoption?
- What gaps exist in the literature, and what future research directions are needed?

Through this synthesis, the review aims to propose a research agenda that explores strategies for integrating AI tools into engineering curricula. These strategies must address faculty development, ethical concerns, and the practical application of AI-driven tools to enhance student outcomes [9], [10]. By synthesizing findings across diverse sources, this exploratory review contributes to the ongoing dialogue on AI's role in engineering education, providing practical insights for educators, policymakers, and researchers. It highlights emerging trends, critical gaps, and strategies for effective integration, ensuring that GenAI's potential is optimized to foster durable skills while addressing ethical and pedagogical concerns.

Background

Generative AI in Education

GenAI is transforming education by shifting from traditional knowledge-based learning to competence-based approaches, where the focus is on fostering problem-solving, creativity, and adaptability [1]. Higher education must now prioritize the cultivation of "generic skills", as emphasized by Wilkinson [11], which include teamwork, leadership, and adaptability—competencies that remain highly relevant even in the age of AI-driven automation. Employers are increasingly identifying skill gaps among graduates, particularly in their ability to integrate AI tools effectively into business and engineering processes [12].

GenAI-powered tools, such as Intelligent Tutoring Systems (ITS) and Virtual Reality

(VR), have shown promise in creating personalized and engaging learning experiences that support essential skill development [13], [14]. However, concerns have been raised regarding overreliance on AI-generated content, which may hinder students' ability to develop higher-order thinking skills if not used appropriately [15], [16]. AI-driven learning environments should, therefore, be designed to support and scaffold student learning rather than act as direct content generators, ensuring cognitive engagement and critical reflection, where GenAI tools provide incremental support rather than direct answers to students' questions, encouraging critical thinking and problem-solving [6], [16].

The versatility of GenAI extends to disciplines such as engineering, computer science, and business, where its ability to generate code, analyze data, and facilitate complex problem-solving positions it as a powerful educational asset [2], [6]. These applications are particularly relevant in engineering education, where students benefit from interactive, application-driven learning environments, such as AI-powered design tools and simulation-based learning, allow students to engage with complex engineering problems in adaptive, real-world contexts [17]. Similarly, AI-enhanced educational platforms, including gamified learning environments, have been shown to improve student engagement and learning outcomes by adapting content dynamically to individual learning needs [7].

Despite these advantages, ethical concerns surrounding GenAI's integration into education must be addressed. Issues related to bias in AI models, data privacy, and the risk of plagiarism have raised questions about the responsible use of AI in academic settings [9]. Heimdal [18] highlights that AI tools can enhance students' critical thinking abilities when used to challenge and refine their problem-solving approaches. However, blind reliance on AI-generated outputs increases the risk of misinformation and plagiarism, necessitating ethical guidelines and AI literacy initiatives for students and educators alike [16]. While AI applications on education are expanding, empirical research on its long-term impact on learning outcomes remains limited [1].

Durable Skills Development in Engineering

The transition to Industry 5.0, which emphasizes human-centric collaboration with AI-driven systems [19], has intensified the need for durable skills in engineering education. These include communication, adaptability, creativity, problem-solving, and teamwork, all of which are essential in navigating rapidly evolving technological landscapes [20]. However, traditional engineering curricula have been criticized for failing to keep pace with the demands of modern industries [21]. Employers increasingly argue that universities remain confined by rigid structures, limiting their ability to prepare students for an AI-augmented workforce.

GenAI presents both opportunities and challenges in this regard. On one hand, AI-powered personalized learning can foster self-directed learning and metacognitive skills, enabling students to develop problem-solving strategies tailored to their individual needs [22].

By incorporating GenAI into active learning environments, educators can promote metacognitive strategies that improve both technological proficiency and durable skills such as adaptability and collaboration [23]. On the other hand, concerns persist regarding whether AI-generated content discourages independent thinking, potentially leading to passive learning experiences if improperly implemented [15], [24].

One key advantage of GenAI in engineering education is its ability to simulate real-world problem-solving scenarios [3], [5], [25]. AI-driven adaptive learning systems can dynamically adjust complexity levels in problem-based tasks, allowing students to engage with progressively more challenging content [23]. Additionally, collaborative AI tools enable students to work in teams on engineering design challenges, reinforcing communication and teamwork skills—both of which are vital in multidisciplinary and industry-relevant contexts [26].

The increasing fluidity of career pathways in engineering also underscores the need for lifelong learning and interdisciplinary competence, as AI technologies continue to evolve [27]. Studies highlight a growing shift toward career adaptability, where engineers must continuously reskill and upskill to remain relevant in an AI-integrated job market [21]. This transition demands a holistic curriculum that integrates both technical and durable skills, ensuring that graduates can navigate automation, digital transformation, and AI-driven workplaces [27].

Challenges in Integration

Technical and Pedagogical Limitations

Educators exhibit varying attitudes toward the adoption of GenAI tools in the classroom. While some recognize their potential to enhance learning and problem-solving, others express concerns regarding accuracy, reliability, and ethical implications [2]. Leading universities have begun developing guidelines for AI usage, acknowledging both its promise and risks in education [6].

Some primary challenges using GenAI are reliability and accuracy of generated misinformation, bias in AI models, a risk of overreliance that may lead to a reduction in critical thinking and independent problem solving, and quality control of generative responses [2]. Additionally, there is a risk of overreliance, as excessive dependence on GenAI tools could diminish independent problem-solving, creativity and critical thinking [28]. Ethical concerns also arise, including bias in AI models, transparency in decision-making, and the security of student data, highlighting the need for institutional policies and ethical oversight. Other technical and pedagogical issues that are present in using GenAI are dataset bias, generalization of large datasets, explainability and potential trouble interpreting complex AI model decisions, and factual accuracy in generative content that is not always accurate or reliable [2].

Engineering education faces specific AI-related challenges. In a study by Heimdal [18], engineering students who integrated AI into coursework reported improvements in task

efficiency and knowledge acquisition. However, concerns arose regarding the potential deskilling of students, particularly in manual problem-solving and creative writing abilities. Students also identified risks associated with overtrusting AI-generated information, highlighting the need for AI literacy training in engineering curricula [29]. By addressing these limitations and challenges, the AI research community can better improve the performance and usefulness of language models in GenAI.

Ethical Considerations

Beyond technical concerns, ethical implications surrounding GenAI adoption in education remain a pressing issue. Researchers emphasize the need to examine how AI systems function in real-world educational contexts and whether they align with intended pedagogical goals [30]. Key ethical issues include data privacy and security, as many GenAI models collect and analyze user data, raising concerns about how student information is stored and used. Algorithmic bias is another critical challenge, as AI models trained on biased datasets may perpetuate existing inequalities, disproportionately affecting certain student groups [2]. Academic integrity is also at risk, as the potential misuse of GenAI tools in coursework and assessments necessitates new academic policies to uphold integrity standards [31].

It is essential to note that examining how these AI systems function in real-world contexts and assessing their alignment with the intended purposes under expert supervision is another crucial perspective that merits significant attention by researchers and practitioners in the field [5]. Though GenAI is an invaluable tool in scientific research, ethical considerations must be addressed with its use. If researchers were to improve the technical and pedagogical uses of GenAI, there must be a pathway that is paved for advancing and creating responsible AI-driven applications. Developing robust ethical frameworks will be essential to ensure responsible AI integration in education. Wilkinson [11] argues that understanding AI's limitations is a critical component of graduate preparedness, emphasizing that higher education must incorporate AI literacy training into its curriculum. Furthermore, AI's role in supporting, rather than replacing human skills such as, creativity or critical thinking should be a central pedagogical consideration.

Recent studies have also highlighted the need for reconceptualizing student roles in an AI-augmented learning environment. Huston and Plate [29] propose a shift toward metacognitive training, where students are taught to be effective editors and evaluators of AI-generated content, rather than passive consumers. This approach aligns with the growing human-AI collaboration paradigm, where AI functions as an intelligent assistant rather than an autonomous decision-maker.

Methodology

This study employs an exploratory literature review to examine the role of GenAI in fostering durable skills in engineering education. Given the emerging nature of GenAI research, an exploratory approach allows for a broad synthesis of existing knowledge while identifying

gaps and future research directions. The literature search was conducted across IEEE Xplore, Web of Science, and Google Scholar, using keywords related to Artificial Intelligence, Generative AI, Engineering Education, 21st-Century Skills, and Skill Development. Studies were included if they were peer-reviewed (2023–2024), focused on GenAI in education, and provided empirical or theoretical insights on skill development.

In addition to peer-reviewed sources, this review includes some selected grey literature, such as arXiv preprints, to capture emerging insights in this rapidly evolving field. Following established guidelines [32], [33], the inclusion of grey literature was justified by its relevance, recency, and potential to address gaps in peer-reviewed research on GenAI in education. These sources were critically assessed for credibility and contribution to the thematic synthesis. Data extraction followed a structured rubric, assessing research objectives, AI tools employed, learning outcomes, challenges, and ethical considerations. A thematic analysis was conducted to categorize findings into key areas such as GenAI's impact on skill development, barriers to adoption, and pedagogical implications. To enhance reliability, two independent reviewers analyzed the selected studies, resolving discrepancies through consensus.

Findings

Key Insights

GenAI tools demonstrate significant potential for enhancing durable skills, including critical thinking, problem-solving, creativity, communication, and collaboration. Studies indicate that ChatGPT and similar AI-driven platforms can scaffold learning, prompting students to engage in higher-order thinking tasks rather than providing direct answers [34]. AI-powered simulations and intelligent tutoring systems have been utilized to foster creativity and collaboration in engineering design tasks [27]. Additionally, AI-powered dashboards and adaptive learning environments have provided personalized feedback, enhancing student engagement and skill acquisition [3].

However, despite these promising findings, there is a notable lack of empirical research quantifying the effectiveness of GenAI tools in skill-building [1], [3], [4]. Many studies remain theoretical or exploratory, with limited longitudinal data to assess GenAI's sustained impact on durable skill development ***[2], [8], [35]***. Also, existing studies often lack standardized methodologies for evaluating AI's pedagogical impact, making it difficult to derive generalizable conclusions about AI's effectiveness across diverse educational contexts ***[36], [37]***. Educators also face significant barriers to adopting GenAI tools, including technical limitations, faculty resistance, and institutional constraints. A lack of technical expertise and insufficient faculty training programs hinder widespread adoption [7]. Moreover, concerns about the reliability, fairness, and ethical implications of AI-generated outputs contribute to hesitancy among educators [27]. Institutional barriers, such as limited funding for technology and AI infrastructure, also impede AI integration in engineering education [10].

The integration of GenAI in education also raises critical ethical considerations, including data privacy, algorithmic bias, and the equitable use of AI tools. These challenges are exacerbated by the lack of transparency in AI decision-making processes and the potential for unintended consequences, such as reinforcing educational inequalities or fostering over-reliance on AI for learning [6], [9], [38]. Addressing these concerns requires the development of robust ethical guidelines and institutional frameworks to ensure responsible and equitable AI adoption in engineering education.

Comparative Analysis of Existing Solutions

Case studies reveal varying levels of success in using GenAI tools to develop durable skills. Several studies highlight that intelligent tutoring systems can improve problem-solving abilities by adapting to individual learning needs **[29], [39]**. However, these tools' effectiveness often depends on factors such as the quality of the AI algorithm, user interface design, and the level of integration within the curriculum, where AI must align with pedagogical objectives to enhance, rather than replace, traditional teaching methods.

In addition, faculty attitudes toward GenAI adoption significantly influence its success. While some instructors embrace AI tools for their potential to enrich teaching and learning, others remain skeptical due to concerns about accuracy, ethical considerations, and the time required for training [6]. Institutions that provide structured faculty development programs and establish clear guidelines for AI usage report higher levels of faculty engagement and more successful GenAI integration [10].

Challenges and Best Practices

The findings reveal recurring challenges in integrating GenAI into engineering education, including technical limitations, faculty resistance, and ethical concerns. These challenges underscore the need for targeted interventions to bridge knowledge gaps, standardize evaluation frameworks, and ensure responsible AI integration in educational settings [1]. Effective strategies for integrating GenAI include incorporating faculty development programs that emphasize hands-on training, enabling educators to develop proficiency in AI tools [22]. Promoting collaborative learning environments, where faculty and students engage in co-creation with AI tools is also key, along with interdisciplinary approaches that can foster AI literacy across various engineering domains [5].

For example, the framework presented in [25] provides a conceptual model for aligning AI-driven tools with pedagogical objectives, aiming that both students and educators are equipped to navigate the complexities of modern education. Other best practices include: fostering a culture of experimentation and feedback, where AI integration is continuously assessed and refined; promoting AI literacy, ensuring that both educators and students understand AI limitations and biases; and leveraging AI’s adaptive capabilities, using personalized learning pathways to accommodate diverse learning needs [35], [37].

To overcome barriers to adoption, faculty development initiatives must focus on building educators' confidence and competence in using GenAI tools. Programmatic efforts might include workshops, case studies, and collaborative projects that demonstrate the practical applications of AI in enhancing durable skills. Additionally, investing in creating supportive infrastructures, including technical resources and ongoing professional development opportunities, is essential for institutions [7], [8].

Practical Recommendations

To optimize the integration of GenAI in engineering education, specific pedagogical approaches must be explored and supported. Among these, project-based learning (PBL) and roles-based competency frameworks stand out as promising strategies for fostering durable skills through GenAI-enhanced experiences.

Project-based learning (PBL) is grounded in collaboration, real-world problem-solving, and reflective practice [40]. This approach allows students to apply theoretical knowledge in hands-on contexts, transforming ideas into actionable solutions and fostering a deeper sense of agency in their learning [41]. Students who design their own AI-based solutions to self-identified problems not only strengthen their problem-solving abilities but also enhance their self-efficacy and perceived competence when supported by a PBL framework [41]. The roles-based approach, though relatively new in engineering curricula, has gained significant traction in fields such as medical education. It uses clearly defined roles to describe competencies, promoting task-based learning environments that align knowledge and skills with professional expectations. This approach supports clearer learning objectives and helps students better understand the responsibilities of engineers in diverse and evolving contexts [42].

To enable the implementation of these approaches and foster sustainable GenAI integration, state and federal development programs should be established. These initiatives should include investments in computational infrastructure, such as GPU-based supercomputers for research, and strategic partnerships between academic institutions, industry, and non-profit organizations [43].

Conclusion and Future work

The integration of GenAI in engineering education presents transformative opportunities for developing durable skills such as critical thinking, problem-solving, creativity, communication, and collaboration. This exploratory literature review has synthesized existing research to examine how AI-driven tools, such as ChatGPT and intelligent tutoring systems, influence skill development in educational settings. While the potential of these technologies to revolutionize learning is evident, this review identifies significant challenges that must be addressed to ensure their effective and ethical deployment in engineering curricula. Key insights from this review indicate that GenAI tools can support personalized learning, provide adaptive feedback, and foster active engagement, making them valuable assets in engineering education.

However, the absence of standardized methodologies and a lack of robust empirical studies hinder the ability to measure their long-term effectiveness. Ethical considerations, particularly concerning data privacy, algorithmic bias, and equitable access, must be addressed to ensure responsible implementation.

To bridge the gap between GenAI's theoretical potential and its practical application, targeted interventions are necessary. Faculty development programs should provide structured AI training and pedagogical support to help educators integrate AI-driven tools effectively into their teaching practices. Interdisciplinary research collaborations must be encouraged, fostering partnerships between AI experts, educators, and industry stakeholders to develop evidence-based best practices for AI integration in education. Additionally, the establishment of comprehensive ethical frameworks is crucial to guide the responsible use of AI in educational settings, mitigating risks related to bias, academic integrity, and student privacy while ensuring equitable and effective implementation.

Given the nascent and rapidly evolving nature of GenAI in education, further research is needed to assess its long-term implications and effectiveness. Longitudinal studies should be conducted to evaluate the sustained impact of GenAI tools on skill development over time, providing empirical evidence on their role in enhancing learning outcomes. Additionally, research should extend beyond engineering to explore GenAI's applications across diverse educational disciplines, identifying cross-domain best practices for AI integration. Another critical area of study involves addressing the challenges of AI-generated personalization, ensuring that learning experiences remain tailored and adaptive without reinforcing biases. Finally, the development of AI literacy frameworks is essential, equipping both students and educators with the necessary skills to critically engage with AI-generated content and navigate its implications responsibly.

This review addressed the first research question by identifying that GenAI tools are primarily used to support durable skills through personalized learning, adaptive feedback, and real-world problem-solving simulations. In response to the second question, the review outlined key challenges such as faculty resistance, technical limitations, and ethical concerns, including data privacy, algorithmic bias, and academic integrity. Finally, the third question was addressed by highlighting the lack of empirical, longitudinal studies and the need for standardized evaluation methods. These findings inform a future research agenda focused on interdisciplinary collaboration, AI literacy development, and the responsible integration of GenAI in engineering education. Ultimately, this work underscores the need for a balanced approach that leverages GenAI's capabilities while safeguarding human-centric education. By fostering durable skills, ensuring ethical AI practices, and equipping educators with the necessary tools, GenAI has the potential to redefine engineering education and prepare students to thrive in an AI-integrated world.

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