WIP: Gen AI in Engineering Education and the Da Vinci Cube

Tammy Mackenzie, The Aula Fellowship

EcoTech CEO, inventor, MBA, human rights activist, philosopher, and researcher of the intersections between strategic management, institutions, and systems theories.

Dr. Lisa D. McNair, Virginia Tech

Lisa D. McNair is Professor of Engineering Education and Director of Arts and Education at the Institute for Creativity, Arts and Technology (ICAT) at Virginia Tech. She is an executive committee member for a2ru and an editorial board member for Ground Works journal. Her research and teaching interests include developing interdisciplinary project-based learning experiences, building networks between university, industry, and community sectors, and expanding engagement in science, engineering, arts, and design. McNair's current projects include building the Interdisciplinary Projects (IDPro) program and a 3D manufacturing module series in undergraduate engineering at Virginia Tech, framing the da Vinci Cube innovation model, and co-designing tools with communities for collaboration on Alaska housing issues. She earned a PhD in Linguistics at the University of Chicago, and an M.A. and B.A. in English at the University of Georgia.

Rubaina Khan, University of Toronto

Rubaina Khan is a research associate in Queens University and a doctoral candidate in the Department of Curriculum, Teaching, and Learning at the Ontario Institute for Studies in Education (OISE), University of Toronto with a collaborative specialization in Engineering Education. She also has an M.A. in Curriculum and Pedagogy from OISE and an M. Sc. in Computer Control and Automation from the Nanyang Technology University in Singapore. She worked as a senior research engineers at MIT developing navigation technologies for underwater robotics to model and predict environmental issues in the coastal regions of Singapore. As always interested in education, this led her to take up a position as a lecturer at Singapore Polytechnic. She spent the next five years developing interdisciplinary engineering design courses, designing state-of-the-art classrooms, and delivering activities to promote engagement and motivation in the classroom. Her current research interest lies at the intersection of engineering design education, learning communities, and professional identity formation.

Mr. Animesh Paul, University of Georgia

Animesh was born in Tripura, India, and raised in a liberal modern "brown" military upbringing. He prefers the pronouns "He/They" and considers himself a creative, sanguine, and outgoing individual. He graduated with a bachelor's degree in Technology focusing on Electronics and Electrical Engineering from KIIT University. He is now a part of the Engineering Education Transformation Institute as a Ph.D. student under the advisement of Dr. Racheida Lewis. His research is in Engineering Education, focusing on equity, inclusion in the classroom, and easing student transition to the workforce catering to STEM graduates.

Dr. Sreyoshi Bhaduri, Private Corporation

Dr. Sreyoshi Bhaduri is an AI scientist. Currently, she spearheads innovative research in applying generative AI to solve complex supply chain logistics and operations challenges. Her expertise spans applied statistics and natural language processing, with a PhD from Virginia Tech and specialized training in Responsible AI from MILA. Sreyoshi has been recognized as a Graduate Academy for Teaching Excellence (VTGrATE) Fellow, a Global Perspectives Program (GPP) Fellow, and was inducted in the Bouchet Honor Society in 2017. Sreyoshi is committed to demystifying and democratizing generative AI solutions and bridging the gap between theoretical research and practical applications using AWS technologies.

Work-in-Progress: Gen AI in Engineering Education and the Da Vinci Cube

Abstract

As generative AI (GenAI) tools rapidly transform the engineering landscape, a critical question emerges: Are current educational innovations adequately preparing engineers for the socio-technical challenges of the future? This work-in-progress paper presents two key contributions. First, we build on prior work presenting a systematic review of over 160 scholarly articles on GenAI implementations in engineering education, revealing a predominant focus on enhancing technical proficiency while often neglecting essential socio-technical competencies. Second, we apply an emerging framework—the da Vinci Cube (dVC)—to support engineering educators in critically evaluating GenAI-driven innovations. The dVC framework extends traditional models of innovation by incorporating three dimensions: the pursuit of knowledge, consideration of use, and contemplation of sentiment. Our analysis suggests that while GenAI tools can improve problem-solving and technical efficiency, engineering education must also address ethical, human-centered, and societal impacts. The dVC framework provides a structured lens for assessing how GenAI tools are integrated into curricula and research, encouraging a more holistic, reflective approach. Ultimately, this paper aims to provoke dialogue on the future of engineering education and to challenge the prevailing assumption that technical skill development alone is sufficient in an AI-mediated world.

1 Introduction

We take as our starting premise that engineers have a responsibility to society, and consequently, that engineering educators have a responsibility to convey this to their engineering students. However, there are few measures for determining how these responsibilities that span socio-technical boundaries can be integrated into research in engineering education (henceforth, EE). 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 surveyed the opportunities of and challenges for GenAI in higher education (e.g., [1], [2], [3], [4], [5]), a significant knowledge gap still remains in engineering education. Specifically, we are investigating how researchers are approaching questions about the role of GenAI in engineering education.

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 [6]. As such, post-secondary institutions are dealing with issues like resource constraints around designing curriculum and evaluation strategies [7] [8] [9] [10], ensuring equitable and inclusive access to learning [11] [12] [13], and providing flexible pathways for fresh graduates [14] [15] [16]. Significantly, given public financing cuts on education around the world [17], and the repercussions from the recent pandemic [18] [19], institutions are finding ways to innovate using GenAI as a learning technology. The use of machine learning and natural language processing in engineering education research and classrooms is not new [20] [21] [22] [23]. 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 [24], to facilitate resource allocation [25], and to enable higher engagement with students through personalized mentoring [26]. These promising use-cases have led to large-scale investments, disrupting traditional ways of learning and tutoring [27].

However, GenAI has raised concerns among educators and institutions, primarily dealing with plagiarism [28], renegotiating the role of instructors [29], and ethical concerns, for example around using student data [30]. These tensions have led researchers to beseech developers to create solutions that speak to systemic barriers [31], employ transparent methodologies [32], and co-design with educators [33]. In recent research in EE, the issues discussed above are prevalent along with calls for EE programs to ensure that their graduates have the technical skills to develop products and processes embedded in complex systems that work seamlessly [34]. Further, these systems must be developed with sustainable mindsets and use ethical design methodologies [35]. However, such sophisticated teaching and learning expectations are not always adapted to the realities of large classroom sizes and budget constraints. Therefore, GenAI holds both promise and challenges for engaging learners from various backgrounds with dynamic, personalized, and effective tools [36]. Further research

is needed to explore the performance of GenAI tools in teaching epistemic content [37] and in the context of the professional skills needed in industry [38], and to engage in the critical thinking required to solve "wicked" problems [39]. Lastly, EE training needs to show the implications of GenAI and engineering work in a society [40] that requires development of human values [41], empathy development [42], lifelong learning [43] and taking on responsibility for sustaining our planet [44].To map early patterns in EE-based research on GenAI, we frame the findings of a systematic literature review within the dVC framework that foregrounds the dimension of Contemplation of Sentiment. Our work in progress paper thus offers a comprehensive summary of key innovations and motivating perspectives.

2 Methods

2.1 Building on a Systematic Literature Review

We chose a systematic review to highlight the range of applications, key pedagogical approaches, and motivations for GenAI integration in engineering curricula and classrooms. The review [45] uses the Search-Screen-Appraise approach [46] as visualized in Figure 2, 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 ([47]) 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. Results of this work are reported in detail elsewhere (blinded for review).

2.2 da Vinci Cube Framework

The da Vinci Cube framework is a novel approach that extends the traditional Pasteur's Quadrant model [48] by introducing a third axis: Contemplation of Sentiment [49–51]. In development through a qualitative user study, the new framework is designed for exploring the drivers of innovation and incorporating the crucial role of emotion, human-centered, and ethical considerations in decision-making processes and actions of individuals and organizations.

Stokes's Pasteur's Quadrant expands two axes - basic research and applied research - into a model that highlights the possibility and prevalence of basic and applied research overlaps (as in Louis Pasteur's work). However, this approach still neglects the complex aspects that drive human behavior and decision-making. The da Vinci Cube framework addresses this limitation by incorporating a third axis that explicitly considers sentiment and visually expands the quadrant into a cube. This new model recognizes that emotions, values, and ethics play a vital role in innovation - shaping organizational culture, product design, hiring practices, and individual development. By acknowledging and analyzing this third component and driver of innovation, the da Vinci Cube framework provides a more comprehensive and nuanced understanding of the motivations that drive innovation by individuals and organizations.

Our team recognized the potential of applying the da Vinci Cube framework to enhance our systematic review. We applied its principles to explore patterns across the included papers in terms of pursuit of knowledge, consideration of use, and contemplation of sentiment. Specifically, we sought to investigate to what degree the innovations in engineering education addressed the emotional and ethical aspects of teaching and learning in relation to technological advances and skills development.

3 Results

Our systematic review (details: [45]) revealed a diverse and rapidly evolving landscape (see Figure 1). 45 papers 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 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.

At a high level, applying the da Vinci Cube model reveals that while many of the papers in the largest category of Coding Assistance are motivated by "quest for knowledge" (basic research of developing new programming and identifying needs for code correction), such knowledge acquisition was often done with "consideration of use" (applied research in

pedagogical contexts). Likewise, research in the category of Design Methodology explored and innovated ways of creating new technologies for a range of contexts (knowledge and use), which entailed consideration of ethical standards. When proposing and creating ethical guidelines, researchers were operating in an area that required "contemplation of sentiment." Finally, in the categories of position papers and miscellaneous, researchers considered student and teacher motivation, components needed for personalized learning to work, and other topics that required contemplation of sentiment. Importantly, none of the research in any categories engaged in one sole axis but rather involved multiple and intersecting drivers.

The following subsections provide descriptions of categories identified in the systematic literature review and organized as categories in Figure 1.

3.1 Coding Assistance

Our review uncovered a significant concentration of research on GenAI based coding assistance applications in engineering education. We found three broad sub-categories with 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., [52], [53], [54]), creation of customized and ready to use programming exercises(e.g., [55]) or even attempting to distinguish between human-generated or AI code (e.g., [56–58]) 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 ([59]) and a Human Centered AI approach to understand how post-primary students in Ireland engage with GAI tools ([60]). 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., [61], [62], [63]). 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.

3.2 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, [64] 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 [65], making ethical choices during prototyping in time-sensitive situations such as hackathons [66], and learning disciplinary skills needed for design projects through personalized learning [67]. 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 [68].

3.3 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 [69] advocated for enhancing GenAI in Data Science through prompt engineering, another [70] 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 [71], specifically addressing trust in AI for programming tasks [72], and pointing out technical limitations of GPT models in educational distribution systems [73]. Non-empirical studies included in these review examined the promise and ethical considerations of GenAI [74] and advocated for a balance between benefits and risks. Others [75] 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 [76], highlighting the need for more assessments of GenAI in engineering education [77], proposing future scenarios for AI in software development, emphasizing productivity and ethical concerns [78], and suggesting a co-evolutionary approach to GenAI in human creativity [79]. 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.

3.4 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., [80–82]. 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 ([83–85]. 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., [86–88]). Some studies examine how AI tools are changing students' information-seeking and learning behaviors ([89, 90]. 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., [90–92]). 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., [83, 84, 91]). 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.

3.5 Writing Assistance

7 studies explored the use of ChatGPT for generating or scoring text-based content in EE. Similar to the papers under Coding Assitance, 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 [93]. Some studies ([94] [95]) 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 [96], students showed increased motivation, improved learning performance, and positive attitudes towards the AI-generated scenarios, aligning with findings on a similar study [97] related to AI-augmented learning.

3.6 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 [98] compared the results of various LLM responses to mechanical engineering exam questions while another [99] 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., [100], [101]). 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 [102] demonstrate how co-creation requires building up mutual understanding, in a way very different from a usual relationship between an artist and their tools.

As an example of intersecting drivers, our initial findings of the papers showed that engineering educators found immediate relevance of GenAI applications in scaffolding the learning process, especially of technical skills, through just-in-time feedback and epistemic guidance. These findings align with the premise that AI-enhanced personalized learning systems providing feedback and guidance can be tailored to individual students based on progress, learning preferences, demographics, and interests. However, for these tools to find mass relevance across engineering institutions, researchers note that just-in-time value to what educators need and aspire to have in their classrooms is necessary. Therefore, it is

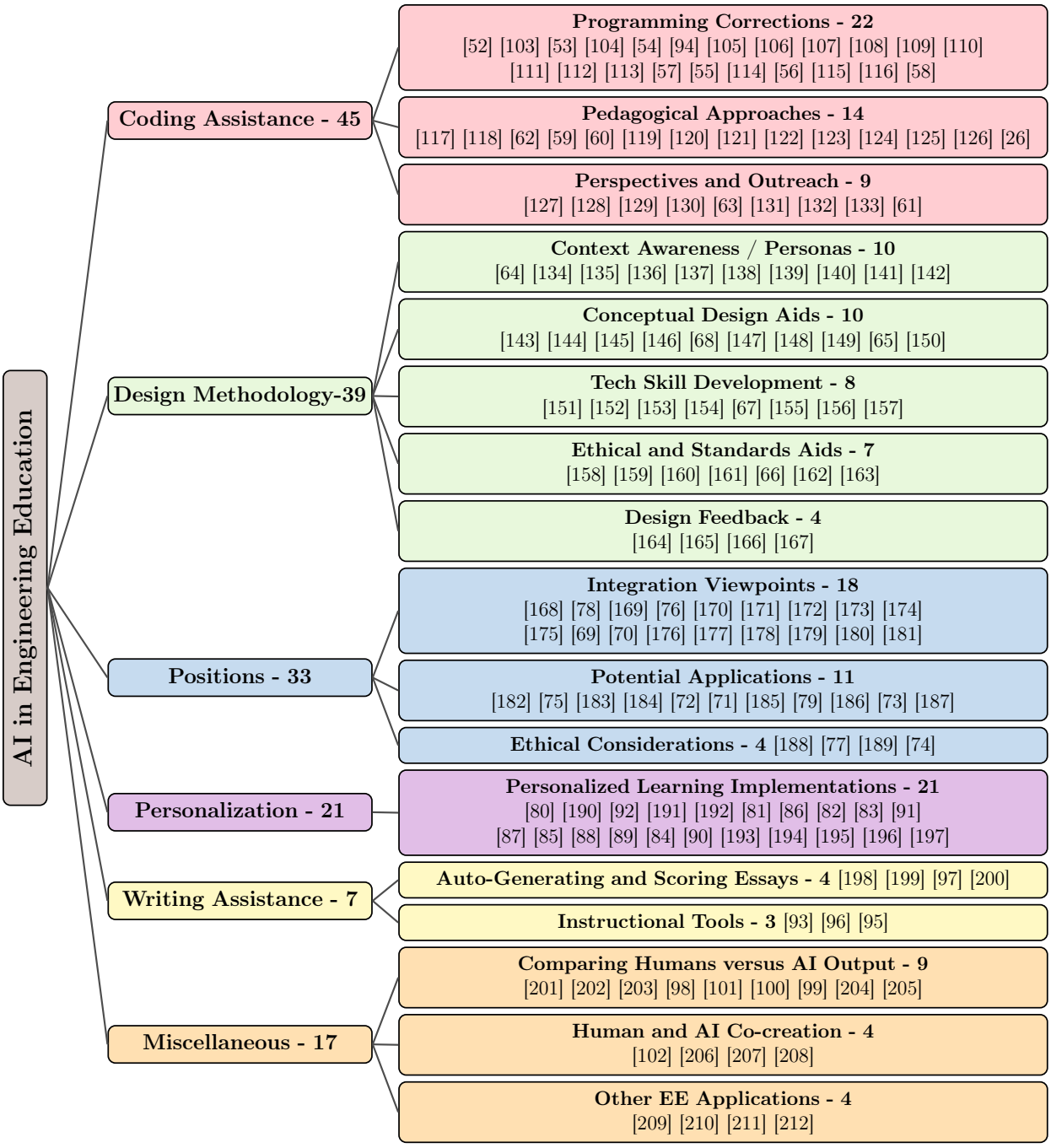

Figure 1: This taxonomy categorizes 162 papers describing the use of GenAI in Engineering Education (EE) into six broad objectives: Coding Assistance, Design Methodology, Positions, Personalization, Writing Assistance, and Miscellaneous

essential that our community focus on designing tools and learning systems that close the feedback loop between students and educators with meaningful outcomes related to ethics, societal values, and other considerations.

4 Limitations

Integrating the in-development da Vinci Cube framework into our systematic review was challenging in terms of practical implementation. The model's initial testing is being conducted using qualitative analysis of 60-minute transcripts of interviewees exploring the model with a researcher. Translating the early data into an instrument that operates reliably in a systematic task will require further development. For example, our team implemented a reflection process to develop a rubric for future assessment that provides consistency on the linguistic level of analysis, subject of analysis, and interpretation of the sentiment construct. Linguistically, the model does not lend itself to analysis at the lexical level, but works well when a subject focus is employed. For example, while words or phrases such as "feel" or "we hope to" lack relevance when lifted out of context, using the model to focus on components of research studies - such as articulation of problem statements, methodologies, discussion of results, and conclusions - revealed drivers of research that more readily aligned with the axes of Quest for Knowledge, Consideration of Use, and Contemplation of Sentiment. As we further employ the model as a way to characterize patterns of research in a particular field focus, we also expect to refine the meaning and usage of the construct of "sentiment" itself, which will be necessary to distinguish and explore intersections between sentiment, use, and knowledge in different contexts.

5 Conclusion

The integration of Generative AI (GenAI) in Engineering Education (EE) presents both unprecedented opportunities and significant challenges that demand careful consideration. Our research highlights the need for a comprehensive, multi-disciplinary approach that bridges technical innovation with human-centered educational practices. Several critical areas emerge as priorities for future research, including the investigation of how GenAI impacts the development of engineering identity, addressing algorithmic bias and equity concerns in AI-generated educational content, and examining the implications of technological access disparities. The path forward requires systematic user experience research with both educators and students, focused on developing adaptive, personalized learning environments that respond to individual needs, while evaluating the effectiveness of GenAI-enhanced educational interventions.

Our ongoing work will focus on expanding the research corpus to enhance the comprehensiveness of our analysis, refining the da Vinci Cube framework application to engineering

education, and developing a practical rubric for analyzing GenAI innovations that considers basic and applied approaches to research as well as drivers that may fall into the evolving construct of "contemplation of sentiment," such as dimensions of emotion, empathy, human-centric design, and ethical considerations.

The future of engineering education lies in the thoughtful integration of GenAI technologies with evidence-based pedagogical practices, requiring intentional research that ensures inclusive, effective implementation while maintaining focus on core educational objectives. This approach will be crucial in preparing engineers who can navigate and shape an increasingly complex socio-technological landscape. To achieve these goals, future research will necessitate interdisciplinary expertise including education policy, education research, learning sciences, AI, and ethics, among others. A significant emphasis must be placed on developing and testing personalized GenAI-powered learning environments that adapt to individual students' needs and abilities, while simultaneously addressing the ethical implications and overall impact on engineering education. Through continued investigation and framework development, we aim to equip educators and researchers with tools to evaluate and implement GenAI solutions that enhance learning outcomes while addressing ethical considerations and maintaining human-centered educational values.

Our ultimate goal remains to provide a comprehensive framework for understanding the evolving landscape of GenAI in engineering education, ensuring that this technological advancement serves to strengthen rather than diminish the human elements of engineering education. The development of an easy-to-use rubric built on the da Vinci Cube framework will facilitate the systematic analysis of GenAI innovations, enabling researchers and practitioners to better understand and navigate the complex interplay between drivers of innovation in engineering education, including knowledge, use, and sentiment.

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