Professional Preparation of Students for the Integration of AI into the Practice of Civil and Environmental Engineering

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Abstract

The Center for Infrastructure Transformation and Education (CIT-E) held an online workshop on August 21, 2024 titled "Professional Preparation of CEE Students for the Realities of AI in the Workplace." Sixty-eight participants attended, mostly faculty and staff from civil and environmental engineering departments in North America.

The workshop included a facilitated conversation. Responses were collected using the online collaboration tool Mural (www.mural.co) and provided a rich set of information regarding how to prepare our students for the near future.

We augmented the available information from Mural with a follow-up "pulse" survey to practitioners and faculty, with the objective of working toward consensus on defining the skillset and mindset needed by future civil and environmental engineers with respect to the use of AI.

Background

Since the 1950's researchers have been collaborating across many disciplines to better understand how Artificial Intelligence (AI) can provide efficient problem-solving pathways when modeling and optimizing [1]. The American Society of Civil Engineering has a long history of promoting the use of computing power in civil engineering with documented use in the 1950's in the defense program, the space program, and the interstate highway system [2].

More recently, the rise of AI over the last decade has signified a paradigm shift across nearly all industries, with transformative impacts on how businesses and professions operate, innovate, and grow and boosting the productivity for the Civil and Environmental Engineering (CEE) industry [1],[3]. As we as professionals continue to integrate AI into real-world implementation, it has the potential to foster safer, more sustainable, and more efficient infrastructure systems and construction practices, ultimately reshaping the future of the built environment.

AI broadly refers to computer systems' ability to perform tasks that typically require human intelligence. It includes both computational AI and embodied AI [2]. Computational AI has evolved to encompass Machine Learning (ML), Natural Language Processing (NLP), Computer Vision (CV), and other specialized techniques. Its applications are many and include predictive analytics, image and pattern recognition, optimization algorithms, natural language interfaces, and autonomous systems. The integration of AI has the potential to unleash productivity gains by automating routine tasks, enhancing data-driven decision-making, and enabling predictive systems to address complex challenges with greater speed and precision. A 2023 McKinsey report highlighted AI's potential to contribute between $2.6 and $4.4 trillion annually to the global economy, with significant implications for traditionally conservative fields, including civil engineering [4].

In CEE, AI has begun to shift to long-standing methods of infrastructure planning, construction, and maintenance, offering powerful tools to tackle pressing challenges such as aging infrastructure, resource constraints, and climate resilience. For example, AI-driven predictive models allow engineers to forecast material performance or structural demands under varying conditions with unprecedented accuracy [4], [5]. The adoption of generative design algorithms enables accelerated optimization of infrastructure layouts while considering multi-dimensional constraints like cost, sustainability, and environmental impact [6]. Advanced computer vision systems now automate visual inspections for bridges, roads, and other critical infrastructure, reducing the time and human error associated with conventional methods. These advancements underscore AI's growing importance as a disruptive force in civil engineering, and by extension, the urgent need to prepare future professionals to effectively harness its capabilities. And, civil engineers can be aided in the development of infrastructure by using AI to work with large data sets full of noise, complex and ill-defined problems, and nonlinear functions [7].

Embodied AI, on the other hand, focuses on how to ground algorithmic innovation in a physical system and automatically execute a set of tasks. For example, construction robots enable the automation of both independent skillful manipulations and human-cooperative construction activities [1], [8]. Robots are also evolving to carry out automated material localization tasks, 3D printing, and assembly to enable modular construction [9], [10].

Role of CIT-E in preparing students for the future of AI

The Center for Infrastructure Transformation and Education (CIT-E) is a community of practice (CoP), whose members share a passion for infrastructure education. Their goal is to transform the way CEE topics are taught. Currently, the CoP is supported by a website (www.cit-e.org) and a model Introduction to Infrastructure course on Canvas. The model course consists of 43 lessons that are grouped into five categories: Fundamentals, Water, Energy, Transportation, and Capstone. In Spring 2021, a survey was conducted among the CIT-E CoP, which revealed that over 4,000 students have been impacted by the group, and that respondents are enthusiastic about improving their understanding of and pedagogical skills related to addressing issues that connect infrastructure and social justice in the classroom [11].

Since 2020, CIT-E has paid particular attention to the role of civil engineering education in ensuring ‘equitable infrastructure.’ The CoP has held four summer workshops (in 2020, 2021, 2022, and 2023) focused on the relationship between civil engineering and equity. Lessons in the model Introduction to Infrastructure course that support equity conversations include: Social Impacts of Infrastructure; Complete Streets; Flint, Michigan Case Study; and Impacts of COVID-19 on Transportation and Stakeholders case study. Additionally, a bibliometric database that lists known publications relating to equity and civil engineering education has been published [12], [13].

The community of practice continues to be a resource to support CEE faculty in responding to new trends, and to that end sponsored an online workshop in 2024 on preparing students for CEE practice in the age of AI. This workshop provided attendees with an overview of AI and the state of AI in CEE practice, and crowd-sourced skills and mindsets needed by future practitioners in the age of AI. Participants learned how AI is being utilized currently in the practice of civil and environmental engineering and developed an understanding of best practices related to first-time implementation of AI. Participants crowd-sourced the following: potential future use-cases for AI in CEE education; the skillset needed in our students to add value to these use cases; the mindset needed by our students to add value to these use cases; and resources and supports needed by our students to be successful in this new 'era.'

Approach

To gain a better understanding of the potential use cases, skills, mindsets, and faculty support resources needed to improve the utilization of AI in civil engineering, the CIT-E CoP hosted a summer workshop on the topic of AI.   On August 21st, 2024, the CIT-E Professional Preparation of CEE Students for the Realities of AI in the Workplace workshop was hosted digitally and 68 CIT-E CoP members provided input via a live discussion and then a Mural board. The Mural board was used to democratize the input process and document the community input. Participants were provided time to brainstorm, post, discuss, and vote on the posts of others.

For the various use cases, voting consisted of hearts and 'thumb-up' icons. One round of voting involved users simply stating which items they 'loved' the most which they showed with a heart icon (each attendee could use up to three heart icons); likewise, the thumbs-up icon was used by participants to identify the items which they thought would have the most positive impact on society (each attendee could use up to three thumbs-up icons).   To provide input on the value of the various mindsets and skillsets, participants used only one icon, the heart, to rate their favorites.

The Mural was designed to inform a pulse survey which would be disseminated to a larger audience after the workshop. In December 2024, a pulse survey was sent to practitioners and faculty members. The pulse survey was distributed to the CIT-E mailing list (348 recipients) posted on the first author's Linked-In page, and all authors sent it to people in their LinkedIn professional network, and professional societies such as ASCE's Education focused committees. The pulse survey asked respondents to categorize different skill sets and different mindsets as "High Priority – Essential," "Medium Priority – Important," and "Low Priority – Useful but Optional." The list of skill sets contained 11 items and the list of mindsets contained 9 items; items on the list were informed by input from the Mural and related discussion at the summer workshop. For each list, respondents were restricted to categorize no more than four items as "High Priority – Essential." Respondents were not restricted in the number of "Medium Priority – Important" or "Low Priority – Useful but Optional" items that they categorized.

Results - Mural

As shown in Figure 1, participants first crowdsourced current and potential use cases for AI in Civil Engineering. A content analysis was conducted on the Mural by the research team to synthesize the collective input of 68 participants. Many use cases can be found in previous literature, and a few novel use cases were noted which are likely to show up as more work is documented. The most popular use cases were: "determining potential social/equity impacts of new projects”, “lifecycle cost estimates based on various decision parameter options”, and future cost projections from ongoing maintenance decisions”.

The most highly favored skillsets were “critical thinking”, “understanding of infrastructure as a network” and “thorough understanding of the problem being addressed”. The most highly favored mindsets were “continuous learning mentality”, the arguably related mindset of “curiosity”, “ability to understand these are tools, not knowledge”, and “scrutiny/verification of accurate information”. Please note that these Mural results are not to be quantified in an interval or ratio manner in which one vote is half of two votes. The Mural was used to inform the survey which is limited to reduce character count and time to complete and increase response rate participant completion.

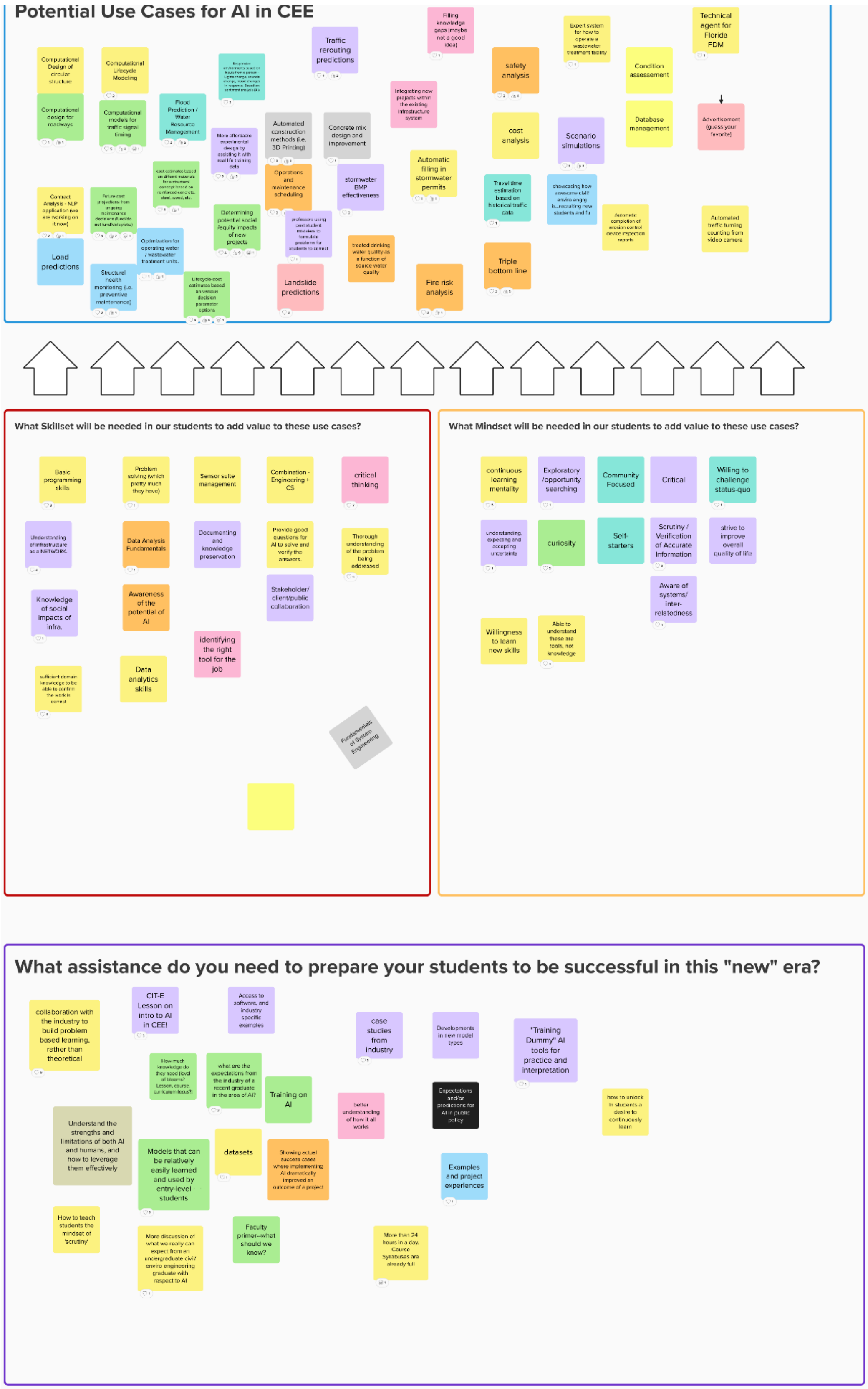
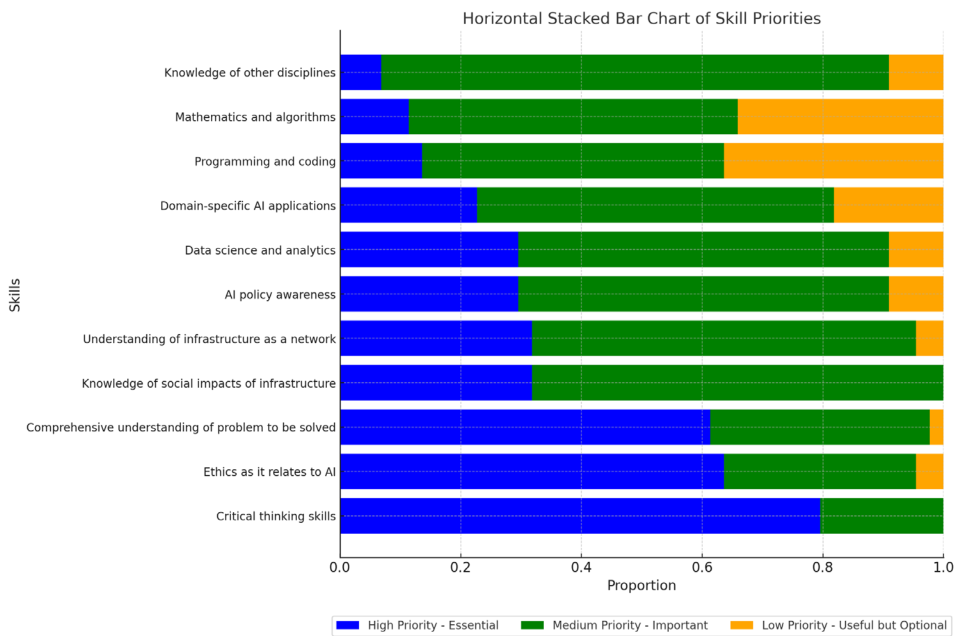
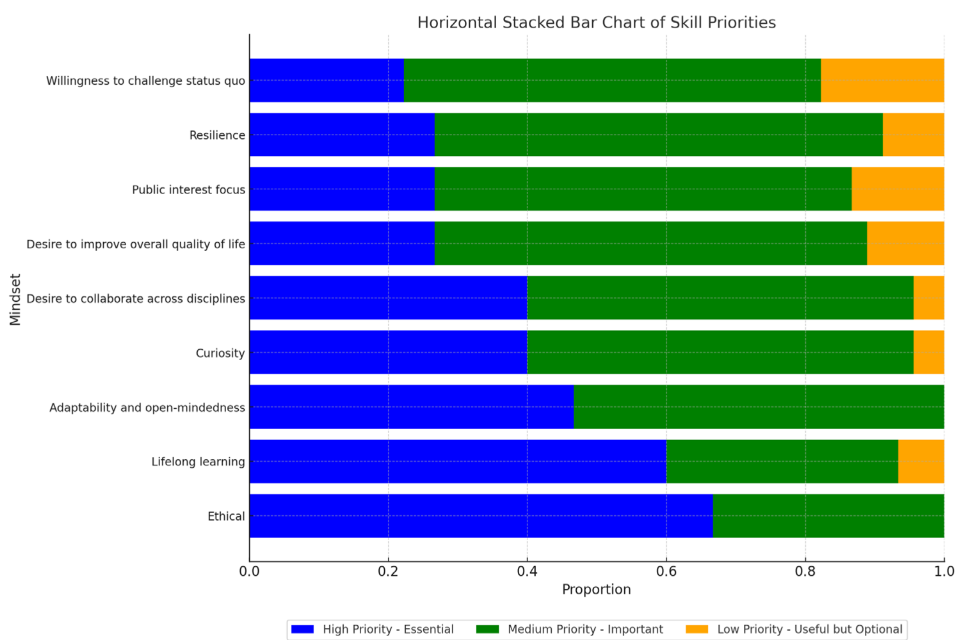


Figure 1: Mural from Summer Workshop

Results - Pulse Survey

We collected a total of 44 responses. 81% of the respondents rated four skills as "High Priority – Essential" and 65% of respondents categorized four mindsets as "High Priority – Essential." The following two figures illustrate the percent of respondents who categorized each item as High, Medium, or Low priority. For example, for "Knowledge of other disciplines", 3 respondents (3/44, or 7%) categorized it as High Priority, 37 respondents (84%) categorized it as Medium Priority, and 4 respondents (9%) categorized it as Low Priority.





Discussion

Observation of the results suggested the following focus areas for our discussion:

- the three skillsets that stand out to us are critical thinking skills, ethics, and a comprehensive understanding of the problem to be solved;
- Mathematics and algorithms and Programming and coding had a relatively large number of responses that categorized them as Low Priority;
- the three highest rated mindsets (ethics; lifelong learning, and adaptability/open mindedness) offer interesting insights.

Skillset: Critical Thinking

Critical thinking is a cornerstone skill for both engineering as well as the integration of AI effectively into our practice, enabling professionals to approach AI tools not as opaque, unquestionable systems but as valuable aids subject to informed scrutiny and validation. As AI becomes more prominent in predictive modeling, design optimization, and data analysis, the ability to critically assess AI-generated outputs is paramount to avoiding overreliance on "black-box" algorithms that may amplify biases, inaccuracies, or misaligned assumptions. For example, a structural engineer using an AI tool to identify stress points within a building design must have the critical thinking skills necessary to scrutinize the underlying assumptions and limitations of the model, as well as its real-world applicability [14]. Critical thinking allows civil engineers to discern where and when AI should be applied, particularly in complex, high-stakes projects where understanding local site conditions, stakeholder needs, and regulatory requirements cannot be fully captured through data alone.

Civil engineers also need critical thinking to navigate the ethical challenges posed by AI adoption, such as the societal impacts of infrastructure decisions influenced or automated by AI. Without a robust framework for evaluating outcomes from an ethical and systemic perspective, AI could reinforce inequities in resource allocation or neglect community-specific considerations [15]. Fostering critical thinking within the next generation of civil engineers ensures not only technical competency but also the ability to make sound, ethical, and impactful decisions in the AI-enhanced workplace.

Skillset and Mindset: Ethics

Engineering ethics has been a topic of focus for the National Academy of Engineers and the United Nations demanding that the engineering education system develop a future workforce that can build an environment which justly serves all with food, water, energy, and information [16], [17]. Updates to ABET standards require civil engineering departments to illustrate their ethics education efforts [18], but there is limited room in current ~120 credit hour civil engineering curriculum. Partial solutions for civil engineering ethics issues have been provided, but wholistic strategies are greatly lacking [19]. For faculty members who prioritize ethics in engineering, complexity is a major barrier for progress. Each year a new group of students comes into departments who differ from their predecessors. People progress over time, and understanding the possible permutations for successful ethical development is a major challenge for both students and faculty.

Consider three major challenges facing the teaching of ethics in engineering education.

1. There are dueling arguments for *when* students should learn engineering ethics. Some think the student experience should be "book-ended" in first year and senior capstone courses to allow for discrete emphasis. Others believe ethics education should be integrated in all courses, or "externalized" and covered in electives offered by other departments like philosophy and sociology.
2. Faculty members can select from multiple pedagogical approaches when deciding *how* students should learn. Active learning increases student autonomy, providing diversity of thought in the classroom and deeper ethical development [20]. Another critical dimension of how students learn is distance and online learning. New opportunities for access to information and instructional modalities are developing in parallel, also including artificial intelligence powered learning aids. This paper provides evidence for cases suited for active learning and online pedagogical approaches.
3. There are multiple theories on the personal ethical development process for assessment protocols to be based on [21], [22], [23]. It is highly improbable that a one-size-fits-all solution exists. Instead, we aim to communicate evidence from multiple perspectives and eventually reach expert consensus, which individual instructors can adapt to user preferences over time.

<u>Skillset: Comprehensive understanding/social</u>

Our civil infrastructure, or public works, is a vast system or network. This network may be thought of as including all of the various subdisciplines of civil and environmental engineering – structural, geotechnical, environmental, etc. and understanding that students must be aware of and appreciate the interconnectedness between the physical manifestations of those subdisciplines (e.g. the relationship between a road and the sanitary collection system; the relationship between a mass transit system and an airport). Additionally, networks exist that connect these physical aspects of infrastructure to non-physical aspects (e.g. the sensors and software that manages the timing of a metered on-ramp to a freeway; environmental policy that defines location, or governs relocation, of wetlands). A third category of networks involves the social and political relationships with the built environment (e.g. user preferences for utilizing crosswalks at roundabouts; political pressure intended to influence location of a transportation facility).

The CIT-E CoP has long posited that students must understand the relationship between these components of the civil infrastructure network in order to be effective engineers (e.g. [24], [25]). Too often, and if at all, it is not until their capstone design experience that students are exposed to the idea of infrastructure as a system. To that end, the CIT-E model course includes specific topics related to systems (e.g. Lesson 3 – Infrastructure as a System; Lesson 5 – Social Impacts of Infrastructure; Lesson 31 – Society and Energy) as well as capstone topics that illustrate the systems nature of infrastructure (e.g. Lesson 30 – Cross Harbor Case Study; Lesson 39 – Water/Energy nexus; Lesson 40 – Rural Water Case Study).

Now, with the advent of AI, it is even more important that students understand problems holistically. AI integration with infrastructure will have far-reaching social implications for example. And, positive impacts of AI may be limited if engineers are not aware of the interrelated aspects of infrastructure.

Skillset: Coding/math

The survey also includes two fundamental AI skills: 1) programming and coding, and 2) mathematics and algorithms. Both of these skills are ranked as low priority. As there is no prior research on how the CEE (civil and environmental engineering) community perceives the reasons for this low prioritization, the authors offer the following inferences:

1. The CEE industry tends to view AI primarily as a set of software tools and applications. As a result, professionals in the field often assume these tools will be sufficiently developed and readily available for use, reducing the perceived need for deep knowledge of coding or mathematical foundations.
2. The authors have noted a general lack of interest in learning coding or mathematics among CEE students, and have also observed that some faculty share this lack of interest.

Mindset: Lifelong learning

A mindset of lifelong learning is critical for civil engineers to remain adaptive and competitive in a profession increasingly defined by rapid advancements in emergent technologies such as AI. AI tools and techniques evolve at an unparalleled pace; engineers must continuously update their knowledge and skills to effectively leverage new applications like predictive analytics, generative design algorithms, or automated inspection systems. Lifelong learners are better equipped to stay informed about advancements, critically evaluate new tools, and incorporate them into projects while avoiding obsolescence. This mindset encourages engineers to embrace the interdisciplinary nature of AI, seeking expertise outside traditional civil engineering disciplines, such as data science and machine learning [26]. This adaptability not only enhances professional growth but also ensures that engineers can anticipate and respond to industry trends, emerging societal needs, and new regulatory frameworks tied to technology [27].

Mindset: Adaptability and open-mindedness

A mindset of adaptability and open-mindedness is also critical for civil engineers seeking to integrate artificial intelligence (AI) and other emergent technologies into their profession. As AI tools continue to disrupt traditional workflows, engineers must be open to rethinking long-established processes, embracing novel methodologies, and experimenting with innovative approaches like generative design or AI-driven optimization. Adaptability enables engineers to pivot when technologies evolve, steer projects within dynamic environments, and proactively solve unforeseen challenges, such as interpreting unexpected outputs or integrating AI with existing systems [27]. Meanwhile, open-mindedness fosters a willingness to engage with interdisciplinary perspectives, understanding how insights from data science, ethics, or computer science can enhance civil engineering outcomes. Together, these mindsets empower engineers to leverage AI's potential responsibly while navigating uncertainty, ensuring both technical and societal advancements [28].

Alignment with ABET and ASCE

Although neither the General Criteria nor the Civil Engineering or Environmental Engineering Program Criteria in the ABET Criteria for Accrediting Engineering Programs [18] explicitly list the need for students to be familiar with AI, Criterion 3 (Student Outcomes) does require programs to ensure that students have an ability to acquire and apply new knowledge as needed. Likewise, the Civil Engineering Body of Knowledge [29] does not explicitly call out AI; it does however list the following outcomes that are relevant:

- Critical thinking and problem solving
- Lifelong learning
- Professional attitudes

Recommendations

The findings from the CIT-E workshop and pulse survey provide a insights on how to best prepare CEE students to thrive in a professional landscape increasingly influenced by AI. To ensure students are equipped with the necessary skills and mindsets for the future, the following recommendations are proposed:

1. Integrate Systems Thinking into the Curriculum - CEE programs should emphasize the concept of infrastructure as interconnected systems, illustrating the physical, digital, and social relationships within the built environment.

2. Foster Ethical Decision-Making - Ethics education, aligned with ABET requirements, must highlight the societal impacts of AI-driven infrastructure projects and address inequities that may arise.

3. Promote Lifelong Learning and Adaptability - CEE programs should consider enhancing current efforts at instilling a mindset of lifelong learning, encouraging students to stay abreast of technological advancements and interdisciplinary developments.

4. Enhance Digital Literacy and AI Competency - While programming and algorithmic knowledge may not be a priority for all students, faculty, or programs, foundational courses in AI applications and data science may be appropriate at some institutions.

5. Provide Faculty Development Opportunities - Faculty play a critical role in preparing students for the integration of AI in engineering practice. Institutions and/or communities of practice should offer professional development programs to help educators stay current with AI trends and pedagogical approaches. CIT-E is well situated to address this need.

6. Engage Industry Partners in Curriculum Design - Collaboration with industry professionals can ensure that academic programs align with evolving workforce needs.

Industry input can inform curriculum updates, internships, and capstone projects that reflect current and future AI applications in CEE practice.

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