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Proceedings of the International Conference on Teaching, Learning and Education
Vol. 2, Issue. 2, 2025, pp. 98-108
DOI: https://doi.org/10.33422/ictle.v2i2.1648

ISSN: 3030-122X online

Embedding AI-Supported Critical Thinking and Ethical Reasoning in Environmental Engineering Education

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Abstract

As the use of artificial intelligence tools becomes increasingly prevalent, engineering education must evolve to prepare students for AI-augmented decision-making while developing robust critical thinking and ethical reasoning capabilities. This study investigates the impact of AI integration on students' critical thinking abilities and ethical reasoning in environmental engineering contexts through a mixed-methods approach, involving 73 undergraduate students. The intervention included three key activities: AI-assisted ethical scenario analysis using real-world environmental engineering dilemmas, comparative concept learning where students defined key environmental legislation concepts independently before comparing with AI-generated definitions, and AI-augmented assignment critique where students evaluated their Environmental Impact Assessment work using AI tools before critically analysing the feedback quality. Data collection employed pre-/post-surveys, reflective journals, and assignment assessments to measure changes in critical thinking abilities, ethical reasoning competency, and AI evaluation skills. Findings demonstrate significant improvements in students' ability to identify limitations in AI-generated ethical analyses and increased confidence in challenging AI recommendations when they conflicted with professional ethical standards. Students showed enhanced metacognitive awareness, with several students reporting improved ability to articulate reasoning behind their ethical judgments. Rather than becoming dependent on AI tools, students developed individualised frameworks for evaluating AI reliability in professional contexts. This research provides evidence-based strategies for integrating AI tools into environmental engineering education, thereby strengthening critical thinking and ethical reasoning capabilities, and offers a replicable pedagogical framework for engineering educators.

Keywords: Competency development; Higher education; Metacognition; Technology integration; Self-directed learning.

1. Introduction

Artificial intelligence (AI) tools are becoming increasingly prevalent in engineering education and professional practice (Popenici & Kerr, 2017; Harle et al., 2024). While these tools offer opportunities to support learning and decision-making, concerns remain regarding students' over-reliance on AI outputs and the potential erosion of critical thinking and ethical judgement (Trotta et al., 2023). As AI becomes more embedded in professional contexts, engineering graduates are expected not only to use these tools competently, but also to exercise sound judgement when interpreting and acting on AI-generated outputs (Sadek et al., 2024). This places renewed emphasis on the development of critical thinking, ethical reasoning, and professional responsibility within engineering education.

In engineering education, the development and assessment of critical thinking and ethical reasoning are widely recognised as core graduate attributes. Established frameworks such as the AAC&U (Association of American Colleges & Universities) VALUE (Valid Assessment of Learning in Undergraduate Education) rubrics and discipline-specific approaches to engineering ethics education emphasise students' ability to evaluate evidence, justify decisions, and apply professional codes within complex, context-dependent scenarios (Finelli et al., 2012; Colby & Sullivan, 2008). These approaches foreground higher-order cognitive processes, including evaluation, judgement, and reflection, which are central to professional engineering competence.

The integration of AI tools into higher education has introduced new challenges related to student learning, agency, and academic judgement. Emerging scholarship suggests that while AI tools can support learning through feedback and idea generation, there is a risk that students may adopt AI outputs uncritically if activities are not intentionally designed to promote evaluation and reflection (Kasneci et al., 2023; Cotton et al., 2023). Within engineering education, there is growing interest in using AI not only as a productivity tool, but as a pedagogical mechanism to support metacognition and critical engagement.

These concerns are particularly significant in environmental engineering, where decisions often have direct environmental, social, and public health implications. Graduates are required to balance technical analysis with ethical considerations, regulatory compliance, and contextual understanding (Engineering Council of South Africa (ECSA), 2017; Gwynne-Evans et al., 2021). Despite this, there remains limited empirical evidence on how structured AI-supported learning activities influence students' ethical reasoning, metacognitive awareness, and critical evaluation skills within discipline-specific contexts.

This study responds to calls within the scholarship of teaching and learning in civil and environmental engineering for empirically grounded, discipline-specific pedagogical research that examines how emerging technologies shape student learning and professional formation (Jiménez Rios et al., 2025). It addresses this gap by embedding AI within structured learning activities that explicitly require students to interrogate, critique, and reflect on AI-generated outputs. Rather than positioning AI as an authoritative source of knowledge, the intervention frames AI as an object of analysis, thereby supporting the development of critical thinking, ethical reasoning, and professional judgement.

2. Aims and Research Questions

The aim of this study was to investigate how targeted AI-supported learning activities influence undergraduate environmental engineering students':

a) critical thinking abilities, and

b) ethical reasoning.

The study was guided by the following research questions:

1. How do structured AI-supported learning activities affect students' ability to critically evaluate AI-generated content?
2. How do these activities influence students' ethical reasoning and confidence in professional judgement within environmental engineering contexts?

3. Methodology

3.1 Research Design and Participants

A mixed-methods research design was adopted to capture both quantitative trends and qualitative insights into student learning. The study involved 73 undergraduate students enrolled in an environmental engineering module at Stellenbosch University, South Africa. Approximately 50 students consented to participate in the survey components of the study, representing a response rate of 68%.

Ethical clearance was obtained under the Stellenbosch University Engineering Graduate Attribute Project (SEGAP-TL-2025-33992). All students enrolled in the module were invited to participate voluntarily and informed of the ethical clearance. Participation in the survey component was voluntary and did not affect course grades. As participation was voluntary, the potential for non-response bias exists. However, demographic comparison indicated that respondents reflected the broader class composition. The surveys were conducted in the presence of the teaching assistant while the lecturer was not present. Students did not have to log into their student account and submissions were captured anonymously.

3.2 Educational Intervention

Three structured AI-supported learning activities were embedded within the module:

Activity 1: AI-assisted ethical scenario analysis

Students were presented with real-world environmental engineering dilemmas and asked to analyse ethical considerations using both their own reasoning and then AI-generated analyses. Students then critically reflected on similarities, differences, and limitations in the AI outputs.

Activity 2: Comparative concept learning

Students first developed their own definitions of key environmental legislation concepts. These definitions were then compared with AI-generated definitions, prompting students to evaluate accuracy, completeness, and contextual relevance.

Activity 3: AI-augmented assignment critique

Students used AI tools to review draft environmental impact assessment (EIA) work and then critically evaluated the quality, usefulness, and contextual appropriateness of the AI feedback.

3.3 Data Collection and Analysis

Data were collected through:

- Pre- and post-activity surveys measuring perceptions of critical thinking and ethical reasoning
- Reflective journals documenting students' experiences with AI-supported tasks

- Assignment artefacts and written critiques of AI-generated feedback

Quantitative survey data were analysed descriptively, while qualitative data from reflections and open-ended responses were analysed thematically.

3.4 Survey Instrument and Reflective Journal Prompts

Students completed a post-activity survey consisting of Likert-scale items designed to capture perceived development in critical thinking, ethical reasoning, and AI evaluation skills. Responses were recorded on a five-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). Table 1 shows a sample of questions asked in the survey. Internal reliability of the survey instrument was assessed using Cronbach's alpha ($\alpha = 0.82$), indicating good internal consistency. Students also submitted short reflective journal entries following each activity. Prompts included:

- "Describe how the AI output compared with your own reasoning."
- "What limitations did you identify in the AI response?"
- "Did the AI change your ethical judgement? Why or why not?"

Table 1: Examples of survey questions

Construct	Example Survey Item
Ethical reasoning	"This activity helped me understand ethical issues more deeply."
Critical evaluation	"I questioned whether AI-generated responses were accurate."
AI judgement	"I trusted the AI's ethical analysis over my own judgement."

3.5 Qualitative Analysis

Reflective journal responses and open-ended survey comments were analysed using thematic analysis following Braun and Clarke (2006). Initial open coding was conducted to identify patterns related to AI trust, ethical judgement, and critical evaluation. Codes were iteratively refined into broader themes reflecting students' perceptions of AI reliability and professional responsibility.

4. Results

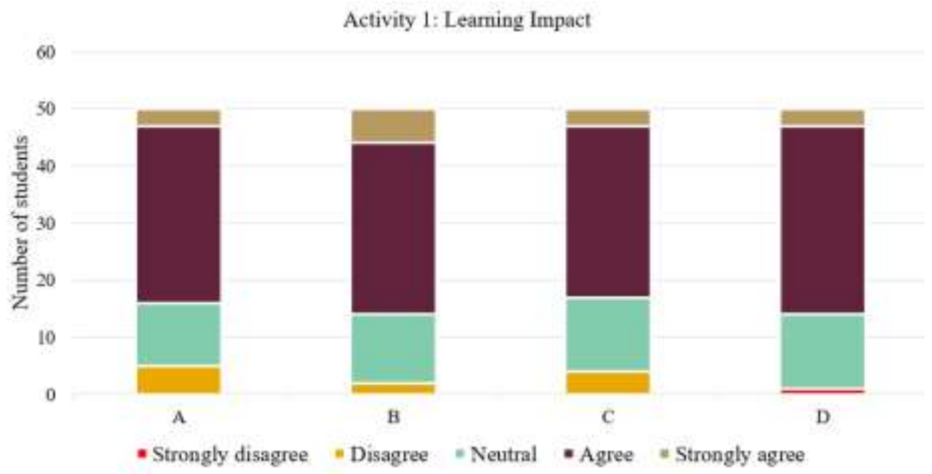
4.1 Ethical Reasoning Development

Survey results in Figure 1 from the AI-assisted ethical scenario analysis indicated that most students agreed or strongly agreed that the activity helped them understand ethical issues more deeply. Students reported that engaging with AI-generated ethical analyses encouraged them to reconsider their initial positions and articulate their reasoning more clearly. Many students (67%) also indicated increased confidence in discussing ethical issues following the activity.

" I learned that AI can not always be trusted and that one should trust your own judgements and not rely on the AI answers."

Descriptive statistics indicate generally positive student perceptions of the AI-supported activity. The highest agreement was observed for the item indicating that the AI analysis encouraged students to reconsider their initial thinking (M = 3.80, SD = 0.70). Students also reported improvements in ethical understanding (M = 3.64, SD = 0.75), confidence discussing ethical issues (M = 3.64, SD = 0.72), and critical thinking about ethical problems (M = 3.64, SD = 0.72).

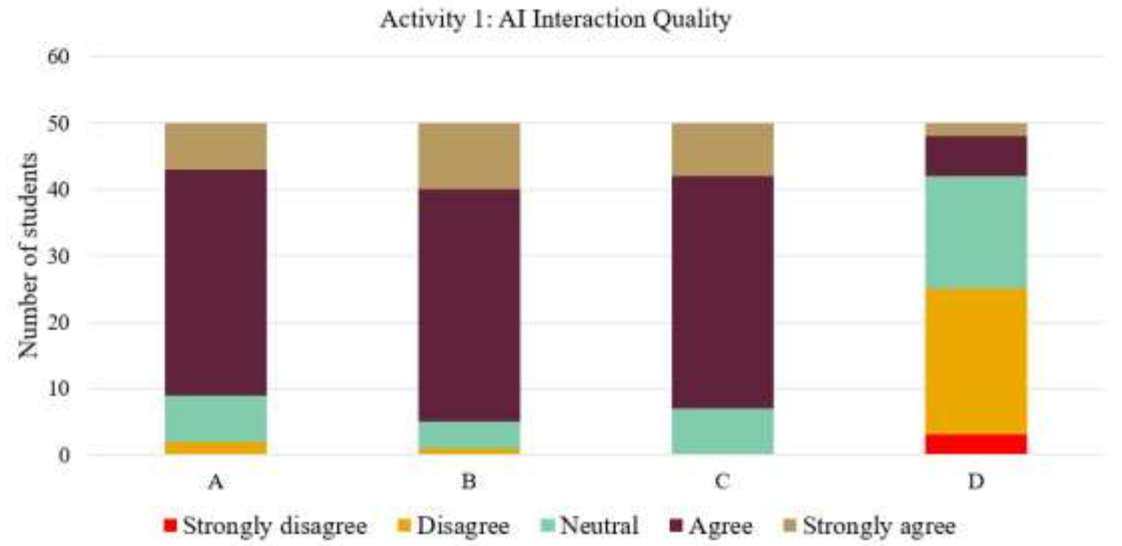
Figure 1: Student responses indicating perceived development of ethical understanding following the AI-assisted ethical scenario analysis



	Description	Mean	Standard Deviation (SD)
A	This activity helped me understand ethical issues more deeply	3.64	0.75
B	The AI analysis encouraged me to reconsider my initial thinking	3.80	0.70
C	I felt more confident discussing ethics after this exercise	3.64	0.72
D	This activity improved my ability to think critically about ethical problems	3.64	0.72

In Figure 2, while students generally found the AI tool easy to interact with and capable of providing useful insights, trust in AI outputs remained conditional. Notably, fewer students (50%) agreed that they trusted the AI's ethical analysis over their own judgement, suggesting that the activity successfully disrupted assumptions of AI authority. This pattern indicates that students were able to engage critically with AI outputs, recognising their value as prompts for reflection rather than definitive ethical guidance. Students generally perceived the AI tool as useful and easy to interact with. The highest agreement was observed for the statement indicating that the AI tool was easy to use (M = 4.08, SD = 0.60), followed by the perceived relevance of AI responses to environmental engineering contexts (M = 4.02, SD = 0.57). However, trust in the AI's ethical judgement remained comparatively low (M = 2.64, SD = 0.95), suggesting that students retained confidence in their own professional judgement rather than relying solely on AI outputs.

Figure 2: Student perceptions of the usefulness, relevance, and trustworthiness of AI-generated ethical analyses

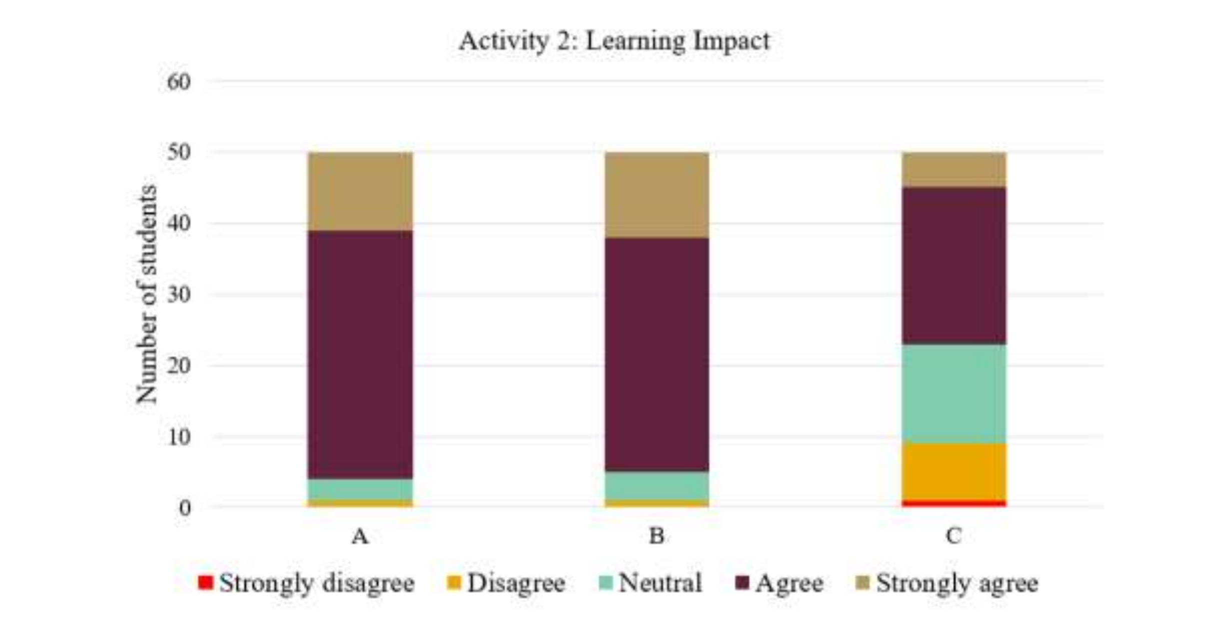


	Description	Mean	Standard Deviation (SD)
A	The AI provided useful insights for the ethical scenario	3.92	0.66
B	I found it easy to interact with the AI tool	4.08	0.60
C	The AI responses were relevant to environmental engineering contexts	4.02	0.57
D	I trusted the AI's analysis of the ethical issues over my own opinion	2.64	0.95

4.2 Critical Thinking and AI Evaluation Skills

In the comparative concept learning activity, students demonstrated improved ability to identify discrepancies between their own understanding and AI-generated definitions (Figure 3). Most respondents (70%) agreed that the activity taught them to be critical of AI-generated content, rather than assuming correctness. Students reported actively questioning which definitions were more accurate and why, indicating enhanced metacognitive awareness. Students reported strong learning gains from the comparative concept learning activity. The highest agreement was observed for the statements indicating that comparing definitions improved understanding (M = 4.12, SD = 0.71) and helped identify gaps in knowledge (M = 4.12, SD = 0.75). Agreement was slightly lower for the statement indicating that students learned more from the activity than from the lecture alone (M = 3.44, SD = 0.80), suggesting that while the activity supported deeper engagement, students still recognised the complementary role of traditional instruction.

Figure 3: Student perceptions of learning gains from comparative concept learning using student- and AI-generated definitions

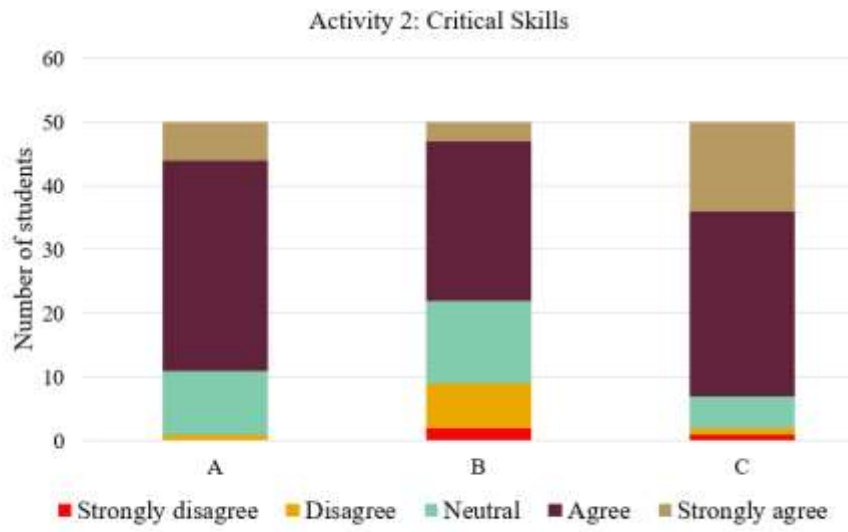


	Description	Mean	Standard Deviation (SD)
A	Comparing my definitions with AI improved my understanding	4.12	0.71
B	This exercise helped me identify gaps in my knowledge	4.12	0.75
C	I learned more through this activity than from the lecture alone	3.44	0.80

Disaggregation of responses shows that the strongest agreement was associated with students' ability to identify differences between their own understanding and AI-generated definitions, followed closely by their willingness to question which definition was more accurate (Figure 4). This suggests that the comparative concept learning activity supported higher-order cognitive processes, including evaluation and metacognitive monitoring, rather than simple knowledge acquisition. Importantly, students reported learning gains that exceeded those typically associated with lecture-only delivery, highlighting the added pedagogical value of structured AI engagement.

Students reported strong engagement in critically evaluating AI-generated definitions. The highest agreement was observed for the statement indicating that the activity taught students to be critical of AI-generated content (M = 4.10, SD = 0.80). Students also reported that they were able to identify differences between their own understanding and AI-generated definitions (M = 3.88, SD = 0.65). Agreement was somewhat lower for the statement indicating that students actively questioned which definition was more accurate (M = 3.40, SD = 0.88), suggesting variation in students' confidence in evaluating competing explanations.

Figure 4: Student self-reported critical evaluation of AI-generated definitions

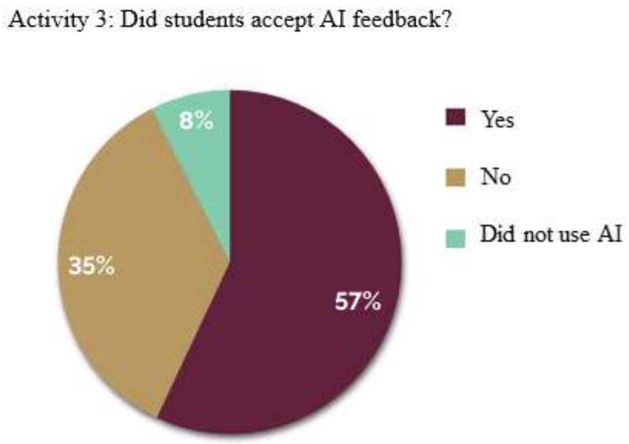


	Description	Mean	Standard Deviation (SD)
A	I could identify differences between my understanding and AI's definitions	3.88	0.65
B	I questioned which definition (mine or AI's) was more accurate	3.40	0.88
C	This activity taught me to be critical of AI-generated content	4.10	0.80

4.3Engagement with AI Feedback

The finding that only 57% of students accepted AI-generated feedback without reservation (Figure 5) is particularly significant. Rather than indicating resistance to AI, this result reflects students' emerging capacity to evaluate feedback quality critically, especially in relation to contextual relevance and professional judgement. Student reflections emphasised that while AI was useful for identifying structural or organisational issues, it struggled to account for site-specific constraints and regulatory nuance, reinforcing the centrality of human expertise in environmental impact assessment practice. Qualitative responses highlighted concerns about lack of contextual sensitivity, proportionality, and site-specific knowledge. One student noted that while AI feedback was useful for identifying structural issues, *"professional judgement and site-specific knowledge are essential skills in the development of an EIA, something AI tools struggle to replicate."*

Figure 5: Student acceptance of AI-generated feedback during the AI-augmented assignment critique



5. Discussion

The findings suggest that structured AI integration can strengthen, rather than diminish, students' critical thinking and ethical reasoning when learning activities are intentionally designed. Rather than positioning AI as an authoritative source, the activities framed AI outputs as objects of critique, encouraging students to interrogate assumptions, limitations, and ethical implications.

Students' increased confidence in challenging AI recommendations aligns with broader calls for responsible AI use in engineering education, where human judgement remains central (Plevris, 2025). The development of personal frameworks for evaluating AI reliability further suggests that students were not merely learning to use AI tools but were cultivating reflective and independent professional identities.

To support replication of the intervention, the AI-supported activities were designed to encourage students to critically evaluate AI-generated outputs rather than accept them as authoritative answers. Students were first required to develop their own responses to ethical scenarios or conceptual questions before consulting AI tools. They then compared their reasoning with AI-generated responses and reflected on similarities, limitations, and contextual gaps. Prompts such as *"Provide an ethical analysis of this environmental engineering decision using professional engineering ethics principles"* were used to structure engagement with AI. Assessment emphasised critical evaluation and justification of professional judgement rather than reproduction of AI outputs. Table 2 contains example criteria used in this study.

Table 2: Example criteria used to assess critical engagement with AI-generated content

Criteria	**Description**
AI critique	Ability to identify limitations or inaccuracies in AI responses
Ethical reasoning	Ability to justify decisions using engineering ethics principles
Context awareness	Consideration of environmental or regulatory context
Reflection	Explanation of agreement or disagreement with AI outputs

This approach positions AI as a tool for reflection and critique rather than a substitute for professional judgement.

The study findings contribute to the growing scholarship of teaching and learning in civil and environmental engineering, reinforcing the need for pedagogically grounded approaches to AI integration that foreground ethical reasoning and critical reflection (Jiménez Rios et al., 2025).

6. Conclusion

This study demonstrates that structured AI-supported learning activities can enhance undergraduate environmental engineering students' critical thinking, ethical reasoning, and confidence in professional judgement. Students gained skills in identifying AI limitations, articulating ethical concerns, and questioning AI-generated outputs rather than accepting them uncritically.

The findings offer practical implications for engineering educators seeking to integrate AI responsibly into curricula. By designing activities that explicitly require critical evaluation and ethical reflection, educators can ensure that AI serves as a learning support rather than a substitute for human judgement. The approach presented here is readily transferable to other engineering disciplines and educational contexts.

Acknowledgment

1.1 This paper is an output of a project supported by the Vice Dean of Teaching and Quality Assurance, in the Faculty of Engineering at Stellenbosch University. Ethical clearance was obtained under the Stellenbosch University Engineering Graduate Attribute Project (SEGAP-TL-2025-33992 [July 2025 - 2029]).

References

Cotton, D. R. E., Cotton, P. A., & Shipway, J. R. (2023). Chatting and cheating: Ensuring academic integrity in the era of ChatGPT. *Innovations in Education and Teaching International*, *61*(2), 228–239. https://doi.org/10.1080/14703297.2023.2190148

Engineering Council of South Africa (ECSA). 2017. Code of Conduct. Engineering Professions Act No 46 of 2000. *Government Gazette*. 142 (40691). March 17. Government Notice 41. Cape Town. [Online]. Available at: https://www.ecsa.co.za/regulation/RegulationDocs/ Code_of_Conduct.pdf .

Finelli, C. J., Holsapple, M. A., Ra, E., Bielby, R. M., Burt, B. A., Carpenter, D. D., Harding, T. S., & Sutkus, J. A. (2012). An assessment of engineering students' curricular and co-curricular experiences and their ethical development. *Journal of Engineering Education, 101*(3), 469–494. https://doi.org/10.1002/j.2168-9830.2012.tb00058.x

Gwynne-Evans, A. J., Junaid, S., & Chetty, M. (2021). Repositioning ethics at the heart of engineering graduate attributes. *Australasian Journal of Engineering Education, 26*(2), 81–97. https://doi.org/10.1080/22054952.2021.1913882

Harle, S. M. (2024). Advancements and challenges in the application of artificial intelligence in civil engineering: a comprehensive review. *Asian Journal of Civil Engineering, 25*(1), 1061–1078. https://doi.org/10.1007/s42107-023-00760-9

Jiménez Rios, A., Plevris, V., Nogal, M., & Admiraal, W. (2025). Scholarship of teaching and learning in civil and structural engineering: A systematic literature review. *Journal of Civil Engineering Education, 151*(3), 03125001.

Kasneci, E., Sessler, K., Küchemann, S., Bannert, M., Dementieva, D., Fischer, F., Gasser, U., Groh, G., Günnemann, S., Hüllermeier, E., Krusche, S., Kutyniok, G., Michaeli, T., Nerdel, C., Pfeffer, J., Poquet, O., Sailer, M., Schmidt, A., Seidel, T., Stadler, M., Weller, J., Kuhn, J., & Kasneci, G. (2023). ChatGPT for good? On opportunities and challenges of large language models for education. *Learning and Individual Differences*, *103*, 102274. https://doi.org/10.1016/j.lindif.2023.102274

Plevris, V., & Hosamo, H. (2025). Responsible AI in structural engineering: a framework for ethical use. *Frontiers in Built Environment*, 11, 1612575. https://doi.org/10.3389/fbuil.2025.1612575

Popenici, S. A. D., & Kerr, S. (2017). Exploring the impact of artificial intelligence on teaching and learning in higher education. *Research and Practice in Technology Enhanced Learning*, *12*(22). https://doi.org/10.1186/s41039-017-0062-8

Trotta, A., Ziosi, M., and Lomonaco, V. (2023). The future of ethics in AI: challenges and opportunities. *AI and Society*, *38*(2), 439–441. https://doi.org/10.1007/s00146-023-01644-x

Sadek, M., Kallina, E., Bohne, T., Mougenot, C., Calvo, R. A., & Cave, S. (2025). Challenges of responsible AI in practice: Scoping review and recommended actions. *AI & Society*, *40*(1), 199–215.