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Generative AI as a Catalyst for Enhanced Learning Experience in Engineering Education

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ABSTRACT

CONTEXT

The traditional approach to teaching Civil Engineering, particularly Geotechnical Engineering, has primarily relied on textbooks and lecture notes. However, this pedagogy has faced challenges in terms of engaging students, fostering critical thinking, and promoting real-world problem-solving skills. As the field of Artificial Intelligence (AI) has advanced rapidly in recent years, Generative AI models have emerged as promising tools for enhancing the learning experience. These models can create a wide range of content, including customised problem sets, virtual simulations, and real-time feedback, which can aid in addressing the aforementioned educational challenges.

PURPOSE OR GOAL

The motivation behind this research stems from the need to enhance pedagogical methods in Civil-Geotechnical Engineering, particularly in engaging students and fostering their critical reviewing and programming skills as required in the industry practice after graduation from university. With the advent of Generative AI, there is a potential to transform traditional educational practices into more dynamic, personalised, and effective methods. This study attempts to showcase several adopted examples on how Generative AI can be utilised to improve learning experience of students.

APPROACH OR METHODOLOGY/METHODS

In this study, an example of a new assessment task designed to evaluate student understanding of Soil Behaviour and their ability to critically review information produced by a Generative AI model. Moreover, example of students being tasked to write computer codes using MATLAB with the help of a Generative AI is presented. In addition, new suggestions for using Generative AI for creating personalised learning experiences are presented in Geotechnical Engineering subject. AI was also used to set up geotechnical questions that required significant iterations to get them right. Students' performance, as well as their feedback, were collected and analysed, which helped to understand the potential and limitations of AI in creating effective learning activities.

ACTUAL OR ANTICIPATED OUTCOMES

It is demonstrated that use of AI as an educational tool could lead to improved student engagement and performance, indicating that this technology could be an effective supplement to traditional teaching methods. Moreover, outcomes will likely shed light on the potential and limitations of AI in creating effective learning activities, such as generating complex geotechnical questions.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The integration of Generative AI in engineering education can potentially enhance student learning outcomes and engagement. Furthermore, while the use of Generative AI in generating complex learning activities shows promise, it also reveals limitations that need to be addressed, such as ensuring the quality and completeness of AI-generated questions, which adds a new dimension to the ongoing discourse on AI in education.

KEYWORDS

Engineering, Generative AI, Assessment Tasks

Introduction

It is well accepted now that AI language models like ChatGPT have promising potential in engineering education, providing benefits such as language editing, virtual tutoring, and research assistance (Fatahi 2023). In the engineering industry, opportunities have also been identified which include augmenting human intelligence, the ability to automate routine tasks, and improve decision-making processes (Fatahi and Parsa-Pajouh 2023). However, as Qadir (2023) elaborated, their potential misuse in completing assessments necessitates the evolution of assessment strategies to maintain academic integrity while leveraging the productivity these tools offer.

A recent comprehensive Australian study conducted by Nikolic et al. (2023) assessed the use of the AI model, ChatGPT, in engineering education and found mixed results based on subject area and assessment type. They observed that there were certain areas in which ChatGPT performed well, such as passing most online quizzes. However, it struggled with tasks that required project-based, reflective, critical thinking, and research-based writing. Furthermore, they concluded that Chat GPT at the time lacked proficiency in creating visual elements or performing advanced mathematical tasks. Nikolic et al. (2023) then recommended the cessation of online quizzes, which encourage cheating, greater use of assessment formats that are harder to cheat (e.g., lab work), and the implementation of unique learning experiences, such as project-based or experimental assignments. They also encouraged the integration of AI into the education process, if it is done ethically and safely.

Referring to a recent Survey conducted by Amani et al. (2023), in academic settings, most academics and students have used Generative AI, primarily to ask technical and general knowledge questions, and to carry on conversations. Students also reported using it for concept explanations, with some admitting it was used for homework and essay writing. There is comfort with its use in courses; however, Amani et al. (2023) show that perceptions of academic dishonesty have increased since ChatGPT's release, while concerns were raised by students and academics about the model negatively affecting critical thinking and problem-solving skills, though students felt more optimistic about ChatGPT improving academic performance than academics did.

While preliminary insights based on student and academic perceptions indicate potential impacts on critical engagement and analysis, further research is necessary to understand the real effects of Generative AI on these cognitive skills in students. Future studies should explore which practices or combinations of learning activities and assessments, integrated with Generative AI, could enhance students' abilities to engage critically and analytically.

Thus, in this research, the authors aimed to evaluate the extent to which civil engineering students, particularly in the field of geotechnical engineering, engage with and critically analyse assessment tasks that incorporate Generative AI. This is compared to their engagement and critical analysis in ways commonly used in the discipline.

Moreover, assessment-based learning is a teaching method that focuses on evaluating students' knowledge and skills through various assessments such as quizzes, tests, and projects. It is an effective way to measure students' progress and identify areas where students may need additional support. Black and William (2006) demonstrated the effect of formative assessment through many examples. They reported that the consistent aspect across those examples was that attention to formative assessment can lead to significant learning gains.

Christodoulou (2014) expressed that educators need to be 'thermostats, not thermometers'. They should not just take a measurement of where a student is, but make changes depending on where they need to be. This analogy can be a great way to start thinking about assessment for learning. In general, assessment-based learning is considered more effective than lecture-based teaching combined with exams, because it allows students to take an active role in their learning process.

That is the reason, generative AI can possibly help students develop critical thinking skills, encourage them to ask questions, and promote independent learning. Lecture-based teaching, on the other hand, is a passive form of learning, where students are expected to listen and absorb information without much interaction. It can be difficult for students to retain information learned

through lectures alone. Indeed, assessment-based learning provides students with immediate feedback on their progress, which can help them identify areas where they need to improve (Reinmann, 2018). It also allows teachers to adjust their teaching methods based on the needs of their students.

On the other hand, learning from worked examples is an efficient way for students to improve their ability to solve engineering problems (Wu et al., 2022). Learning from others' mistakes is another effective way to better understand engineering theories. Since GPT platforms are developed based on various sources of datasets, they can produce misleading outputs (Bender et al. 2021). With the evolution of search engines, students use more online resources than textbooks to quickly obtain information. To educate the student not to rely heavily on the answers given by ChatGPT, and how to use the platform wisely in improving their learning experience, in this study an example is given to demonstrate the limitation of ChatGPT in solving certain geotechnical problems and demonstrate the mistakes the students may make during their learning process.

Research Methodology

Launching a Pilot Assessment Task Adopting Generative AI

As a pilot project offering during Autumn 2023, for the Year 2-3 Civil Engineering subject Soil Behaviour, opportunity to blend traditional research methods, computational simulations, and generative AI-based tools were explored and students could choose one of the 3 options available for the Research Project Assessment Task, which was 30% of the overall mark.

The objective of this innovative approach was not solely to enrich students' understanding of soil behaviour and sharpen their critical analysis skills. It was also designed as a comparative study, seeking to ascertain variations in students' capacities to critically engage and analyse under different educational methodologies. Furthermore, this approach aimed to aid our comprehension of how the adoption of Generative AI in learning environments might impact students' engagement, particularly when contrasted against their involvement and critical dissection as observed in more conventional, discipline-standard methodologies.

In the traditional research option (Option 1), students were encouraged to delve into a topic from a selection of soil behaviour concepts, summarising their findings in a well-structured presentation. This presentation should include pertinent images, key findings, relevant sources, and case studies for deeper understanding. For this option, students were permitted to use credible, published technical sources, papers, and reports to gather information, and they were required to cite these sources appropriately. While detailed referencing was mandatory and students were cautioned about plagiarism, they were also reminded that the nature of the research demanded a thorough literature review with case studies. However, no specific instructions were given to prohibit them from using any legitimate tools for learning, including available Generative AI platforms.

The second option (Option 2) incorporated computational simulation using the industry standard PLAXIS 2D software. Students create an in-depth report, with sections including an executive summary, introduction, explanation of the model used, the modelling procedure, the results obtained, and the conclusions drawn. Additionally, they discussed any challenges encountered during the project, providing valuable insights for future research directions. Computer simulation using Plaxis 2D were for topics such as Bearing capacity of cast-in-situ pile, Excavation with Diaphragm Wall, Building Construction on top of Soil, and Mat Foundation Near Slope.

Option 3, the newly introduced option and most technologically advanced of the three, invited students to interact with the AI model, ChatGPT, and critically evaluate its responses to detailed questions on selected soil behaviour topics. This comparison of AI responses against authoritative resources such as textbooks and research articles gave the opportunity for students to evaluate the accuracy and relevance of AI-generated information, to uncover any discrepancies or inconsistencies, and to explore the implications and potential applications of AI-produced knowledge.

Moreover, for Option 3, students were given an opportunity to juxtapose the results generated by their PLAXIS 2D simulations with the responses from ChatGPT. In this exercise, students posed a specific question to ChatGPT, detailing the basic data of their model, including geometry and material data, and asked the AI model to predict a foundation's bearing capacity. They then appended their question and ChatGPT's response to their report and included a comparative analysis of the AI's prediction versus their PLAXIS 2D simulation results. This comparison facilitated an assessment of the accuracy of AI responses and offered a platform for students to express their perspectives on any observed disparities.

By comparing the three options, we gain insightful reflections on students' ability to engage critically and analytically with various forms of information. The preliminary results from this innovative teaching practice have been encouraging, suggesting promising potential for AI integration in modern education.

Coding Education through Generative AI

In another subject, Technology Research Methods, for postgraduate engineering and information technology students, two assignments were assigned to 40 students. The first assignment pertained to fundamental programming concepts for engineers. Students were requested to utilise ChatGPT to tackle various coding challenges, including calculus problems, partial differential equations, structured graphics, error identification in provided code snippets, and the interpretation of given codes. Additionally, they were expected to optimise code execution time by reorganising commands and code structures.

For Assignment 2, the focus was on employing specialised toolboxes within MATLAB to address more advanced applications. These applications encompassed a range of topics including creating graphical user interfaces (using app designer), utilising neural networking (nftool), performing optimisation tasks, working with statistics, delving into image processing, and employing genetic algorithms. Students were asked to either use toolboxes in MATLAB or get some help from ChatGPT to assist in the writing of the code for the relevant MATLAB toolboxes. Students were asked to validate the results and write a reflective report. In addition, to proper training, the required notes and instructions were provided to students.

Evaluating ChatGPT's Geotechnical Problem-Solving

To demonstrate the ability of ChatGPT to solve geotechnical engineering problems, a comprehensive test was performed through interaction with ChatGPT. In the test, a three-phase relationship problem was requested. (Soil is a material typically made up of three phases: soil particles, air, and water). Two scenarios were considered: being provided with or without equations. Prompts were also provided to see whether ChatGPT could correct the errors.

Results and Discussion

Harnessing Generative AI to Enhance Critical Engagement

For the assessment of the submitted tasks in the Soil Behaviour subject pertaining to Options 1-3 as elaborated earlier, a comprehensive marking rubric was employed. The rubric comprised of four key components: a detailed introduction to the topic and problem statement (20%), the ability to engage and critically analyse (40%), a clear conclusion and summary (20%), and the clarity, organisation, and coherence of the report (20%). This study particularly focuses on examining both quantitatively and qualitatively the collected data related to the students' ability to engage and critically analyse. Table 1 and Figure 1 show the statistical measures and distribution of student marks for "The ability to engage and critically analyse" for various projects options (i.e., Options 1-3).

Referring to Table 1, the average (mean) mark obtained by students for this aspect of assessment was highest for Option 3, where students interacted with the AI model ChatGPT for their projects. This observation suggests that engaging with AI can effectively facilitate the development of critical

analysis skills and positively influence academic performance. The slight positively skewed distributions observed indicate that the tail on the right side of the distribution (representing higher scores) is longer than the left side, meaning that slightly larger number of students scored below the average for this aspect of assessment, while fewer students achieved higher marks.

This observation is more evident for Option 2 where students utilised computer simulation using Plaxis 2D. The steep learning curve of advanced computational simulations like Plaxis 2D and deeper understanding of the assumption used can lead to lower scores for some students, while a smaller group that masters the tool can score significantly higher when analysing the results, pulling up the average and causing larger skewness.

On the other hand, reviewing the submitted assessment tasks adopting Generative AI and talking to students show that most engaged students formulate meaningful queries after several trial & error and distinguished between useful advice/common misconceptions/errors (more proficient in maths/physics and interpreting the data). However, the least engaged students struggled to articulate their queries (too broad a question) and took AI's responses at face value (no critical assessment or identify errors or misconceptions, difficulty in comprehending the significance of the data).

Table 1: Statistical measures for students' marks for their abilities to engage and critically analyse

Assessment Task Option	Mean (/100)	Standard Deviation	Coefficient of Variation	Skewness
Option 1 - Traditional Research via Literature Survey	67.4	5.74	0.09	0.18
Option 2 - Computer Simulation using Plaxis 2D Software	78.4	4.21	0.05	0.52
Option 3 - Interaction with the AI model ChatGPT for Project	84.7	5.58	0.07	0.17

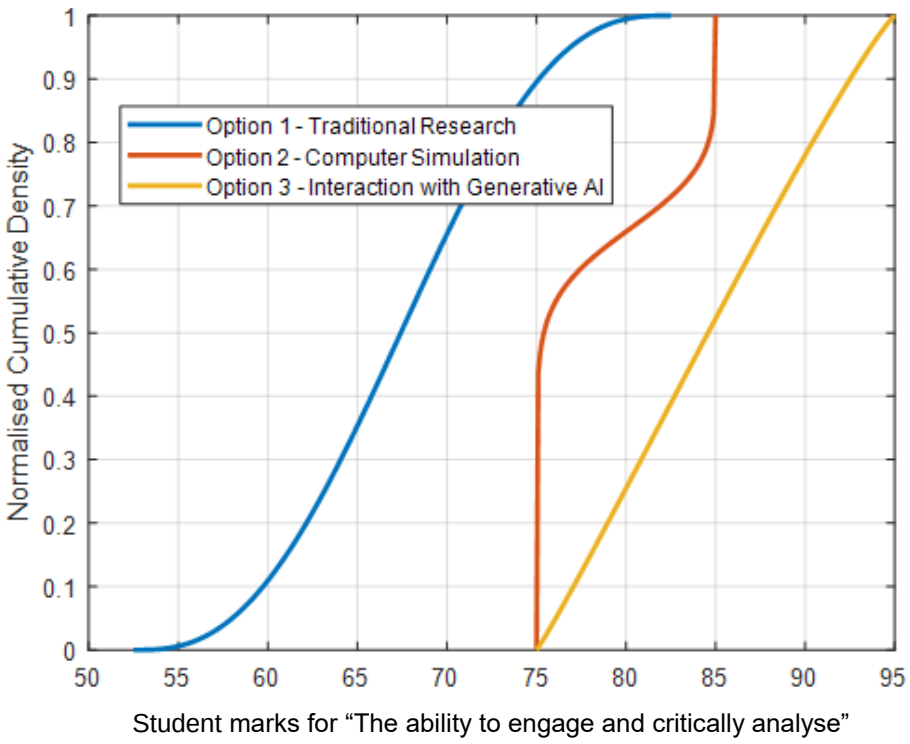

Figure 1: Beta Distribution of the students marks for their abilities to engage and critically analyse in research project assessment task in Soil Behaviour subject

Upon comparison of their own research and modelling to the information provided by ChatGPT 3.5, students made several observations. They noted that ChatGPT is a valuable tool that can offer concise, accurate information when questions are appropriately posed. However, the AI should not be used as the sole source of research as it might sometimes favour precision over completeness. Students emphasised that ChatGPT is best utilised as a supplementary tool to narrow research scope rather than as a standalone resource. They also stressed the importance of cross-checking AI-generated information for accuracy and reliability, as one would with other internet sources. Furthermore, the students pointed out that ChatGPT is a beneficial starting point for basic research in fields such as civil engineering and soil mechanics, and it could point researchers in the direction of additional relevant references.

However, the current version lacks the capacity to provide comprehensive statistical data or concrete research evidence unless specifically asked. The AI system was found to be useful for students and early researchers in gathering brief information, complimenting traditional education methods, and facilitating innovation. In terms of computational accuracy, the students found that ChatGPT's estimations in some cases were reasonably close to their calculations using tools like PLAXIS 2D. However, it was acknowledged that ChatGPT struggles with complex geometric data calculations, thus making it less suitable for complex projects. The AI was also found to be limited in its ability to detail mathematical models or delve into extensive details of complex concepts.

Examples of anonymous comments received from students from a university central platform for collecting feedback are as below:

- *"Really enjoyed the ChatGPT assignment because it showed that the lecturer and the university are accepting of the upcoming technologies and not stuck in the past."*
- *"I also particularly liked the ChatGPT task. It was a new type of assessment format and allowed me to critically analyse the AI tool. I was able to find that the tool didn't go much in detail but rather just skimmed over the question and blabbered on. Tasks like these are really interesting, and I hope to see such tasks in the future."*
- *"The ChatGPT assignment was fun and enjoyable and a good break from the usual structure of assignments. One difficulty I encountered from the assignment was actually finding things that ChatGPT could get wrong. Most questions I asked were correct however the answers were not detailed so there was no chance for the AI to mess up. I had to specifically phrase the question to have ChatGPT explain the science and math behind a certain principle, in order for it to attempt to go into detail and therefore make an error that could be discussed."*

This pilot exercise of incorporating a Generative AI assessment task was positively received by students, who appreciated the use of cutting-edge technology within the learning environment. The assignment promoted critical analysis, with students actively identifying the AI tool's limitations, while enjoying the deviation from traditional assignment structures. Additionally, the unique learning experience helped students understand the state of AI technology and to express a desire for more such tasks in the future.

Empowering Student Learning in Computer Programming through Generative AI

In the next part of study related to coding in the Technology Research Methods subject, students used ChatGPT to generate the required codes for Assignment 1. Continuous review of students' work, and interviewing them, showed that most of the preliminary codes, based on the students' initial prompts, had errors, or included some incorrect equations. However, using well-structured and powerful prompts, with follow up questions, they could overcome most of the errors.

Almost all students, could generate the codes with the help of ChatGPT. Approximately 80% of students could generate complete codes properly. They also provided a reflective report for their attempts, prompts and correction procedures. Feedback from students showed that they found ChatGPT to be very useful for this assessment task.

However, for the second task, they preferred to use MATLAB toolboxes directly and to use ChatGPT only for some fine tuning of Assignment 2. The second task involved intricate

computations that demanded the use of specific toolboxes for resolution. ChatGPT was unable to furnish a detailed approach for tackling it.

The incorporation of AI technology into assessments, particularly through programming, proved to be a fascinating and time-saving endeavour for students. However, it necessitated students to validate outputs and iterate on their code until precise outcomes were attained. Despite the ChatGPT capability to generate appropriate program structures, it was essential to proceed with caution due to the possibility of inaccuracies in certain mathematical and engineering equations provided by ChatGPT. Consequently, a meticulous validation of all equations became indispensable. Fortuitously, the presence of code errors and the subsequent need for rigorous validation present a valuable opportunity for students to immerse themselves in deep learning, thereby enriching their comprehension of concepts, related knowledge, and programming commands.

Generative AI can perform as a virtual tutor, assisting students in their self-study. As a study partner, it can provide step-by-step guidance on problem-solving, offer examples and practice exercises, and give feedback on students' solutions. This feature enables students to have a study buddy available all the time. Bloom's 2 sigma concept, in educational phenomena revealed that the average student tutored one-to-one using mastery learning techniques could perform two standard deviations better than students educated in a classroom environment. Further details can be found in Bloom (1984). Accordingly, the hope is that the generative AI tools can play a supportive role soon in the education of students.

Identifying ChatGPT's Limitations in Geotechnical Problem-Solving

The three-phase relationship of soils (solid soil particles, liquid water, and air) is one of the most fundamental knowledge areas required to understand soil properties, yet most undergraduate students find it difficult due to the numerous equations involved. To examine whether ChatGPT can help students to improve their understanding, a request was sent to the Web version (3.5) of ChatGPT to generate an example and solutions to demonstrate the three-phase relationships of soils. The following example was given by ChatGPT.

> *"Given a soil with a dry weight (ms) of 200 grams, water content (w) of 10%, and specific gravity (Gs) of 2.7, find the volumes of soil solids (Vs) and water (Vw), and the total volume of the sample (Vt)."*

A set of detailed steps was provided but with wrong solutions on the weight of the solids: which was calculated using ms-mw, and Vt was calculated using Vs+Vw. After pointing out that the total volume was wrong, ChatGPT apologized, but gave the same answer without being able to correct it. Further instruction was given to the platform that the void ratio or density of the soil is required to work out the total volume. ChatGPT then corrected the answers and provided an equation with an input of void ratio (e): $Vt = Vs / (1 + e)$. However, the error on the weight of the soil was not corrected.

The question was further raised to ChatGPT: "Isn't the weight of solid the weight of dry soil?" After admitting the mistake, no corrections were made. Then further instruction was provided: "Weight of soil solids = Dry weight of the soil". Only until the following instruction was given, ChatGPT can correct the calculation: "Weight of soil solids = total weight of the soil - Weight of water, not Weight of soil solids = Dry weight of the soil - Weight of water". For the error on the void ratio, $V = Vs * (1 + e)$ has to be given to the platform for it to correct the calculations.

After the interaction with ChatGPT, the same question was provided to ChatGPT (without giving the void ratio). The platform gave the same wrong answer by only correcting the calculation of the weight of solids. But when the void ratio is provided, the platform can give a correct answer.

The example clearly shows the shortcomings of the current version of ChatGPT in producing correct examples to simple geotechnical problems. Since the algorithm is based on a large language model using big data, on one side, it demonstrates a poor understanding of the topic by the majority of the users and, on the other hand, more instructions and training are required for

ChatGPT to provide meaningful guidance. Even after being provided with correct equations, ChatGPT can make mistakes, as it can still be affected by the existing database used in the algorithm. An algorithm needs to be proposed to improve this. On the other hand, it is also a good source for providing examples for students to learn from mistakes and a source of helping them improve their ability to correct others' errors. It is the authors' understanding that many current generative AI tools such as Chat GPT are primarily engineered for language processing and not necessarily mathematical computations, and it was rather remarkable or surprising to see that it demonstrates great potential capability with equations.

Future Opportunities and Recommendations

As this study marked the authors' inaugural efforts to integrate generative AI into engineering education, further work is needed to involve more students, thereby ensuring the collection of more comprehensive and representative data for robust statistical analysis and more accurate comparisons. Regarding the coding assessment tasks, the proposed assessment needs to be fine-tuned after more trials with different cohorts of students to enhance its effectiveness. Sensible measures need to be employed to verify the usefulness of incorporating generative AI tools in assessment tasks. Furthermore, by utilising Generative AI for more advanced coding, students in the TRM subject could be tasked to discover new commands, employ more effective functions, and explore advanced approaches to reduce computation time. Moreover, the example used in the study was generated in ChatGPT 3.5 and the capability of the more advanced version 4.0 or higher needs to be used in future attempts.

Recently, Google introduced Bard as an AI tool. Microsoft improved its AI tool called Bing, which can also provide some references for the generated material. These developments have inspired the authors to employ AI tools in other subjects in the coming semesters. One target is the Geotechnical Engineering subject, a field of practice subject in the Civil Engineering course. The plan is to assign three tasks replacing some conventional tasks in this subject. They are required to utilise three generative AI tools: Chat GPT, Google Bard, and Microsoft Bing, alongside their technical notes, prepared from sound and reliable textbooks in the subject. The tasks are involved with the following steps:

1. Utilise the generative AI tools to perform specific analyses and obtain results.
2. Compare results acquired from AI tools and assess their accuracy against technical notes.
3. Rearrange necessary equations, procedures & comments and include them in the design/reports.

The summary of this proposed endeavour is presented in Figure 2. The students' main objective will be to gain insights into the capabilities and limitations of the generative AI tools and effectively apply their findings in their design and reporting tasks. The summarised steps involve: developing a MATLAB or Python program for soil analysis, determining phase relationships and unit weights with interactive data; detailing various shoring systems for deep excavation, considering differences, advantages, and limitations; evaluating gravity, cantilever, and embedded retaining walls based on AS4678, conducting parametric studies to gauge data effects on wall design, and creating appropriate design codes for each wall type.

According to Sabry et al. (2021), skill transfer from university to workplace involves continuous practice, starting with theoretical learning, then refining during placements, and concluding with reflective classroom reviews. This process ensures effective integration between academic and professional settings. Thus, to align with current engineering professional practices, it is recommended that Generative AI be incorporated into student projects with real life scenarios. By doing so, students can familiarise themselves with the technology and further apply and practice it during placements or in their post-graduation workplaces. Moreover, as elaborated by Khosravi et al. (2022), since advancements in AI have already permeated education, leading to concerns about fairness, transparency, and ethics, adaptation of Explainable AI in educational settings will have significant advantages in terms of student's development, which needs to be explored further.

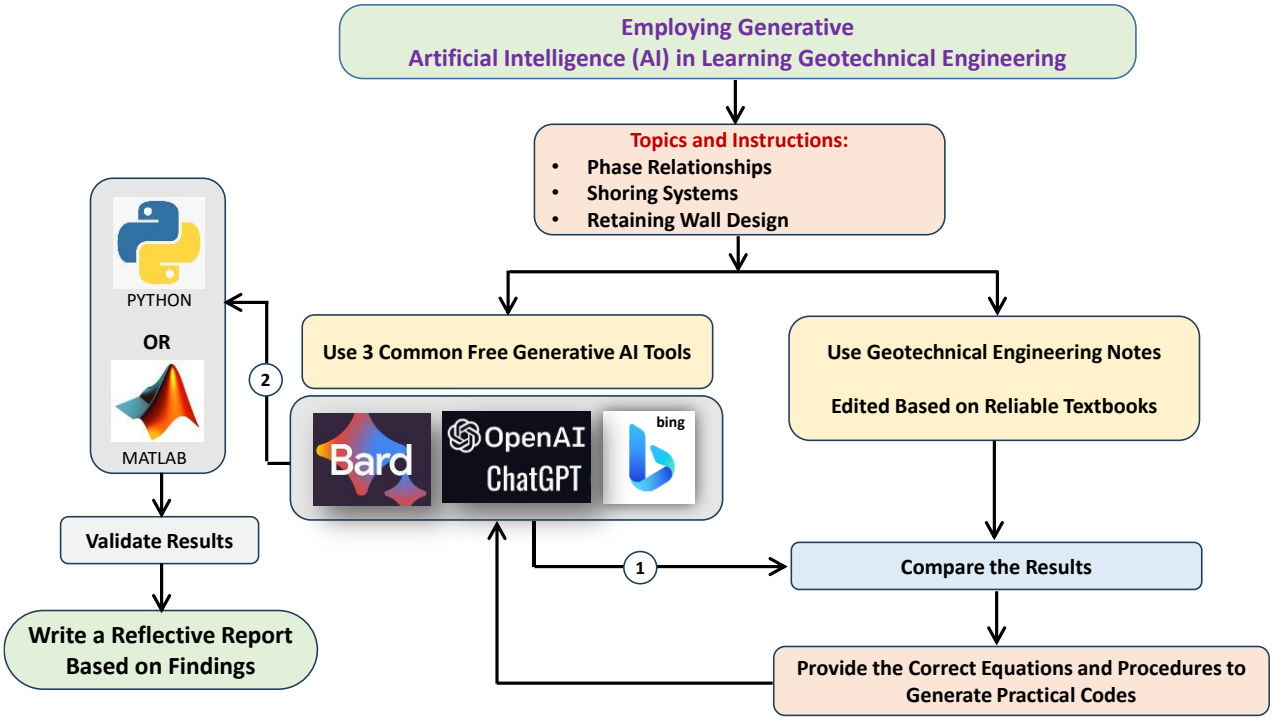

Figure 2. The summary of methodology, illustrating the incorporation of generative AI into geotechnical engineering subject assessment

The students will be asked to validate their results based on solved case studies. Subsequently, they will conduct a parametric study using the generated codes.

Students can receive AI-generated feedback on their write ups, codes, and designs, allowing them to make improvements and iterate on their solutions through smart follow up questions. This iterative process fosters a more robust and comprehensive learning experience, as students can continually refine their work based on AI insights.

Summary and Conclusions

In the Soil Behaviour subject, which is a core civil engineering subject, students were assessed on various tasks through a comprehensive rubric. In this paper we have focused on their ability to engage and to critically analyse (Table 1, Figure 1). Statistical measures of student marks revealed that the use of the generative AI model ChatGPT (Option 3 project) resulted in the highest average scores, suggesting that AI interaction can enhance critical thinking and academic performance. Through their interaction with ChatGPT, students recognised its utility as a research supplement rather than as a primary source. They acknowledged its limitations in handling complex calculations and providing detailed analysis of intricate concepts. The incorporation of generative AI in the learning environment was well-received and fostered critical engagement, indicative of its potential role in future engineering education.

Regarding the coding exercise in the Technology Research Methods subject, students utilised ChatGPT for code generation and, while initial outputs had errors, they could improve results through optimised prompts. Despite ChatGPT's capabilities, careful validation was needed for accurate mathematical and engineering equations, inadvertently fostering deeper student comprehension of the concepts.

Similarly, through a simple three phase relationship problem, the limitations of ChatGPT in solving geotechnical problems were demonstrated. It is a good example to show to the students not to rely heavily on the platform to provide worked examples. On the other hand, it is a good source for producing examples for learning from mistakes.

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