Quest: Human Learning - A Framework for Incorporating Generative-AI Teaching and Learning Instruction in STEM Pre-Service Teacher Preparation (Evaluation)

Abstract

Generative Artificial Intelligence (GenAI) offers tools to transform K-12 science, engineering, technology, and mathematics (STEM) education. Pre-service teachers are in a prime position to learn about and engage with this emergent technology, preparing them to enter the workforce with knowledge on how GenAI can impact K-12 learning outcomes.

This paper examines the implementation of GenAI teaching and learning instruction in a computer science (CS) pre-service teacher preparation program at a small engineering-focused R1 institution. Applying the Quest: Human Learning model, pre-service teachers learned prompt engineering and tested AI output. Quest stands for Question + Test. The pre-service teachers attended the Teach@Mines K-12 STEM teacher preparation program. Teach@Mines offers pathways for undergraduate and graduate students to obtain licensure for teaching in K-12 science, math, and computer science. Students were both undergraduates and graduates. Given the recent advances in GenAI, Teach@Mines asks STEM students to develop innovative future-oriented STEM curriculum and instruction focused on the future of human and GenAI interaction.

This paper uses a case study approach to review curriculum and student artifacts related to GenAI teaching and learning instruction using new AI Education model, Quest: Human Learning (QHL). Case study examples of CS pre-service teachers evaluating, developing, creating, and testing AI-assisted curriculum provide insight into how the QHL model can be applied for other STEM disciplines and pre-service teacher education broadly.

Teach@Mines' implementation of GenAI teaching and learning education in pre-service teacher education empowers future K-12 educators to thoughtfully and responsibly integrate GenAI into the classroom to enhance learning experiences, support diverse learners, and prepare K-12 students for the future. As GenAI advances, applying the QHL model with a focus on teaching future generations provides a novel pathway for STEM majors to reconnect with and define human talents and abilities to solve human problems and develop technological solutions.

Introduction

Generative Artificial Intelligence (GenAI) offers tools to transform K-12 science, engineering, technology, and mathematics (STEM) education. Teachers can use GenAI technology such as ChatGPT to supplement their teaching methods or create content such as course outlines and quizzes; students can use it to help with homework and to receive formative feedback on their work [1, 2]. ChatGPT is a large-lanuage model (LLM) chatbot; it generates human-like text responses based on training from a large amount of data [3]. A March 2023 survey of 1,002 K-12 teachers found that over half of respondents (51%) reported using ChatGPT; almost two-thirds (64%) planned to implement the technology more often [4].

Pre-service teachers are in a prime position to learn about and engage with this emerging technology, preparing them to enter the workforce with innovative knowledge. A recent report by the Center on Reinventing Public Education (CRPE) found that 59% of pre-service teacher programs provided some AI-related instruction; most of the instruction was related to helping future teachers prevent plagiarism [5] . With the recent growth of GenAI, there is a call to prepare educators and students to engage with this evolving technology in productive and ethical ways [6, 7].

Context

GenAI at Colorado School of Mines

This paper examines the implementation of GenAI ethics instruction in a pre-service teacher preparation program at a small, engineering-focused R1 institution offering 14 engineering/STEM majors. Colorado School of Mines (Mines) encourages faculty and students to explore the uses and impacts of GenAI technologies. Instructors can choose to 1) generally permit the use of GenAI tools, 2) generally forbid the use of GenAI tools, or 3) permit the use of GenAI tools for selected assignments. Mines provides model language for faculty to incorporate into their course syllabi to inform students about the GenAI policy for that class [8].

Building on a preliminary survey at Mines in 2023 [9], a second survey of the full student population at Mines in Fall of 2024 found that over 90% of students agree that GenAI should be allowed in coursework [10]. Opinions varied on how GenAI should be allowed; the majority of students agreed that each instructor should select a GenAI policy that is best for each class (59.21%), others thought GenAI use should be restricted to only instructor-specified uses (22.94%), and some agreed that GenAI should be allowed without restrictions (9.62%). Most students reported being moderate users (once or twice, or regularly) of GenAI LLM-powered chatbots (62.80%) while some never used GenAI (17.85%) or used GenAI all the time (12.75%). Students reported using GenAI to learn and understand concepts (39%), replace traditional resources such as textbooks (33%), verify and generate solutions (16%), and summarize text (12%). Figure 1 shows student use of LLM-powered chatbots in learning broken down by department cluster:

- Mech-Civil (n=315, 36.50%): Mechanical Engineering; Civil and Environmental Engineering

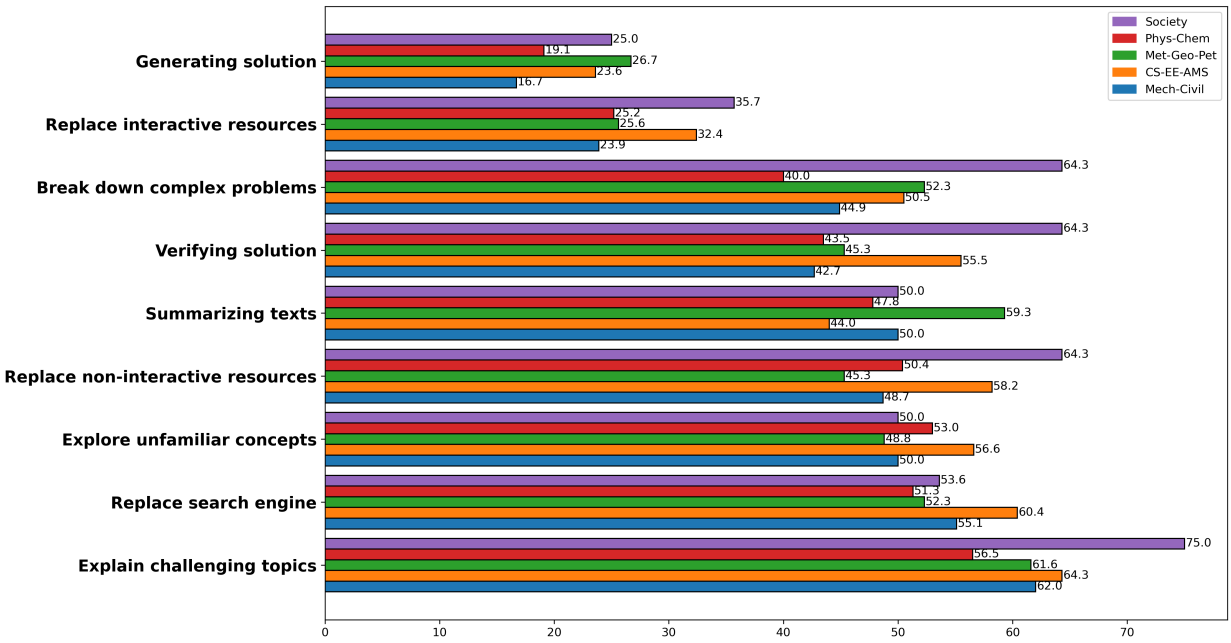

Figure 1: Use Cases of LLM-powered Chatbots in Learning. (Figure replicated from [10].)

- CS-EE-AMS (n=233, 27%): Computer Science; Electrical Engineering; Applied Mathematics and Statistics
- Met-Geo-Pet (n=114, 13.21%): Metallurgical and Materials Engineering; Geology and Geological Engineering; Geophysics; Mining Engineering; Petroleum Engineering
- Phys-Chem (n=167, 19.35%): Physics; Chemistry; Chemical and Biological Engineering
- Society (n=34, 3.94%): Economics and Business; Engineering, Design, and Society; Humanities, Arts, and Social Sciences

Pre-service Teacher Preparation Program

Teach@Mines offers undergraduate and Masters in STEM Education students pathways to obtain their Colorado teaching license in Computer Science, Math, or Science. Licensure requires students to complete 24 credits of education coursework and additional field hours. Students complete three core courses, one teaching techniques course, one teaching practices course, practicum, and student teaching. Students select teaching techniques and practices courses that align with their chosen licensure discipline. The Computer Science (CS) K-12 teacher licensure pathway was the first in Colorado.

Almost 80% of Mines students reported being exposed to CS education prior to their post-secondary education in one or more of the following ways: as a voluntary activity in conjunction with classes in school of activities outside of school; as a required part of the classes in school of activities outside of school; without formal instruction or self-taught. Students reported engaging in such activities across high school (66.28%). middle or junior high school (44.15%), and/or elementary school (17.50%) [10]. Given the expected growth of GenAI in the

workforce and student exposure to CS education, it is important to prepare future teachers to support student learning of GenAI tools at the K-12 level.

Related Literature

Since the advent of LLMs, several authors have recombined human learning theories providing guidance about education with GenAI. In a literature survey of 17 key articles, Noroozi et al.[11] synthesized the promising impacts of GenAI tools that significantly improve educational outcomes via personalized feedback and facilitating language learning. Additional benefits noted were the improvement of learner autonomy, enhancing learning outcomes, and providing administrative and curricular roles. Nayaaba [12] advocates the inclusion of GenAI tools in pre-service teacher education to assist with curricular development freeing up time and energy for teacher educators for pedagogical modeling and learning critical thinking instructional strategies. Focusing on pedagogy and instruction would result in greater constructivist and epistemological learning experiences.

Utilizing GenAI in education presents several challenges along with benefits [13].

- Less critical thinking and information processing.
- High cognitive loads.
- Lack of social interaction and human collaborative learning.

As students learn more with LLMs like ChatGPT, which seemingly converse, care, and have great knowledge, they may miss learning opportunities to process, analyze, and evaluate knowledge. Students who rely on GenAI or interact more frequently with GenAI may fail to learn important social and interpersonal intelligence. Students may fail to evaluate LLM output for accuracy. Students may lose opportunities to ethically evaluate the utility of GenAI data in our human world the more they rely on and trust AI output.

New Educational Model

In visioning a future where teachers, AI, and students interact harmoniously and effectively, a new model of education is needed. The model ideally should place educators at the center of education and enable them to program, guide, and monitor AI. Students should benefit from AI-assisted learning and personalized tutoring. Teachers should be able to see all student + AI interactions and have access to a learning analytics dashboard. Students who need 100% interpersonal learning would have access to a full-time human teacher. All students should test AI output in the real world collaboratively and critically. Students should spend half or more of their learning time testing and applying AI output in the physical world and practicing foundational skills.

Quest: Human Learning

Enter a new learning model - Quest: Human Learning (see Figure 2). According to the model tenets, teachers would engineer learning by prompting AI-tools differentiating for each student. Students would learn how to prompt and query AI virtual teaching assistants (VTAs) to meet their

Figure 2: Quest: Human Learning, Balancing AI and Human Instruction

daily personalized learning outcomes. Then students would test new knowledge and AI output collaboratively with teacher guidance and peers.

Assuming that VTAs continue to improve with GenAI innovations and advancements, teachers may be able to safely rely on VTAs for curriculum development, assessment development, and individualized tutoring. The software to support the ideal QHL learning scenario does not yet exist. However, teachers are beginning to use more AI developed curriculum and tools. Search engines and more platforms are incorporating GenAI. Learning platforms like Khan Academy offer VTAs such as Khanmigo that can write for students, as well as debate and tutor them [14].

Thus, teachers need to prepare learning prompt engineering for administrative and curricular support. Teachers also need to learn how to teach students to learn with GenAI. Teachers have the opportunity with the QHL model to engage students in real-world applications and ethical analyses. Finally, ideally including AI in education may provide much more time for human learning and activities. The QHL model optimizes learning environments and experiences by having students focus on basic fundamental knowledge and skills without computers during the collaborative human learning time. As humans dynamically evolve, AI and quantum computing may provide more time for being human. The QHL model is a pathway for innovative education that embraces the best of learning science alongside AI-assisted learning.

Progression of QHL Inspired Prompt Engineering in Pre-Service Education

In Spring 2024, students in a CS pre-service teaching methods course piloted QHL teacher prompts based on active learning principles and learning science [15]. Similar to the CS constructionist instructional strategy, use-modify-make, pre-service teachers used given curricular prompts, modified prompts for different curricula, evaluated AI interaction and output with prompts, developed prompts through AI-assisted brainstorming, and tested prompts. Specific examples can be seen the Results section.

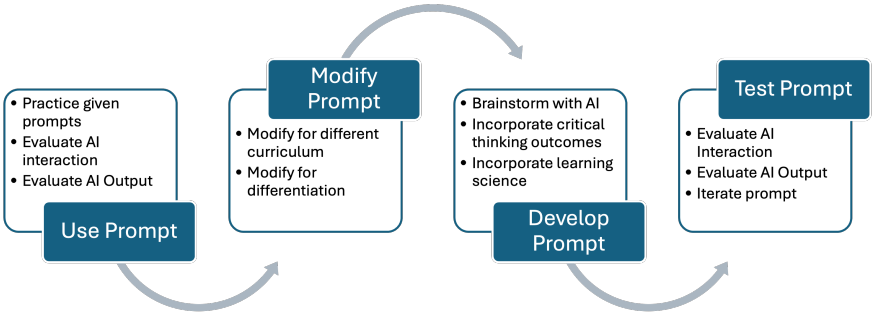

Figure 3: Progression of QHL Inspired Pre-Service Teacher Prompt Engineering

Human Learning STEM Instructional Connections

Many STEM research-based instructional strategies can be applied to the QHL model based on teacher expertise, teaching styles, and learning needs. Here are some examples: During the human learning time designated in the QHL model, students will need to kinesthetically experience learning. In CS education, unplugged activities, where students learn concepts without computers, such as through acting or designing or drawing or talking, provide great ways for students to interact with the physical world and feel learning in their bodies [16].

Teachers can rely on the scientific method and design principles to test AI output and applying AI output in the real world (see Figure 3). Ideally, human learning time with the QHL model would be conducted without computers. Students would be expected to learn and practice long division, handwriting, and critical thinking.

Methods

This paper uses a pilot case study approach to review curriculum and student artifacts related to GenAI education in CS Teach@Mines courses [17, 18]. The case represented in this study was originally defined as Teach@Mines science and CS courses and student work during the 2023-2024 academic year. However, after a general analysis of Teach@Mines courses, the authors refined the scope of the study to provide a courtesy overview of Teach@Mines and then focus on CS education. This change occurred because initial results showed that most GenAI-related content was covered in CS Teach@Mines courses; therefore, focusing on this context from CS courses would provide rich data and results that could be applied to other Teach@Mines courses and extend to other STEM teacher preparation programs.

The authors started by reviewing Teach@Mines pre-service science and CS curricula. They examined course syllabi for mention of learning objectives and/or content related to GenAI. From there, they reviewed course content from the computer science and science teaching courses; they noted coursework related to GenAI and QHL-inspired teaching prompts.

Results

Syllabi Review

The authors reviewed syllabi from all Teach@Mines courses for the courses' GenAI policies and learning objectives related to GenAI. Core courses (common to all Teach@Mines students regardless of disciplinary focus) either did not have GenAI policies or had a policy that did not clearly specify how students were allowed to engage with GenAI: "the GenAI policy for this course will be exploration of how AI may impact education based on our study of educational psychology and assessment." The science teaching courses and student teaching generally permitted the use of GenAI tools, provided the student properly cited their sources. The CS teaching courses and practicum permitted the use of GenAI tools for selected assignments.

The core courses, practicum, student teaching, and the science-focused teaching courses did not include any learning objectives that explicitly mentioned GenAI. The CS teaching courses did contain GenAI learning objectives:

- Students will demonstrate in writing (e.g., lesson plans, reflections, essays) and in teaching presentations knowledge of and/or the ability to effectively instruct: artificial intelligence; computational sciences, computer programming; cybersecurity; data science; hardware and network systems; machine learning; and robotics.
- Students will be able to evaluate the impacts major technological changes have had on society (e.g., internet, mobile phones, AR/VR, AI).

Course Review

Science Courses

The science courses included two assignments that explicitly prompted students to use GenAI tools. The first assignment followed an in-class discussion on culturally and linguistically diverse students; students were introduced to ChatGPT as a potential tool for simplifying language (e.g., making items more concise with bullet points) and how simplifying language can help enhance comprehension for English Language Learner students. As homework, students were given excerpts from two college-level physics textbooks and asked to use the free version of ChatGPT to re-write the excerpts at a 6th grade level. They had to submit the original prompt and output from ChatGPT, note any revisions they made to the original output, and write a reflection comparing the sixth grade versions of the two textbooks.

The second assignment was embedded in the students' final projects. In the project, students were assigned to create a two-week unit plan and wrote four to six lesson plans for a science or math class of their choosing. The GenAI assignment had students use Bing Chat to create initial versions of one to two lesson plans and submit the prompt they gave Bing Chat, the original output, and any corrections they made to the original output. After students submitted the assignment, they were given time in class to reflect on their use of GenAI to create lesson plans.

CS Courses

The following examples will illustrate the progression of QHL-inspired teaching prompts.

Debating AI About Computational Thinking

- *Student Instructions for AI Prompt:* You should begin by asking the AI questions about all four aspects of computational thinking to build the best case in a debate about the best aspect to first teach 5th graders. You will soon be assigned to argue either the pro or the con side, but you won't know in advance which side you will be assigned. The mere fact of preparing for both sides of the debate is a form of active learning which will help you master the material. Ask the AI about both positions until you are comfortable with them. When you are ready, please tell the AI that you are ready for the debate. The AI will begin by providing an argument about the proposition. In response, you should provide a counterargument to whatever the AI asserts. Please record the strongest and weakest arguments made by the AI and explain why you made these judgments in this quiz.
- *Student Observations:* Students evaluated ChatGPT responses of AI arguing the pros and cons of teaching students decomposition and abstraction to 5th graders. Only a few students evaluated the AI answers as strong. Most rated AI responses as marginal or weak. One student noted that AI did point out a few pros or cons that students did not initially consider.

Revising a Prompt for another Course

- *Initial Prompt:* You will play the role of an instructor who is trying to help a student achieve the following learning objective: "Identify the best aspect of computational thinking (e.g., abstraction, algorithms, decomposition, or pattern recognition) to first teach 5th grade elementary students." As a first step, you will ask the human student questions about this topic. Before continuing, wait for the student to type in a question. Then answer the question to help the student build cases for each aspect of computational thinking. Be sure to discuss the pros and cons of each aspect and build a balanced case for the best aspect to first teach computational thinking to 5th graders. When the student is ready, they will tell you they are ready to debate. When the student indicates, choose one aspect at random, "pro" or "con", and tell the student that they will take that aspect. Then you will begin to debate with an argument for the other side. You then begin the debate by taking your side, whichever it is, and providing a good argument for that position. The student will counter with an argument for the other side, and you will provide a counterargument to support your side. Have four exchanges, and then thank the student for a stimulating debate.
- *Revision Instructions:* Revise previous LLM prompt to work better as a review for high school APCSP students and report your prompt. Then evaluate the LLM responses.
- *Student observations:* One student changed the prompt to a "Quiz me…" scenario. One student added in student choice regarding the debate with ChatGPT. Another student gave ChatGPT more specificity with the number of rounds and type of answers.

Evaluate AI Accuracy

- *Student Instructions for AI Prompt:* 1) Examine the output from the following AI prompt

and report on the accuracy of the information. You are playing the role of an AI-tutor helping the learner to master the learning objective, "Computing solutions can have impacts (personal, ethical, social, economic and cultural) based on their use." Different learners prefer different levels of complexity and sophistication, so first offer three versions of a summary of the objective in the context of social media; the versions should be a high, medium, and low levels of sophistication and complexity. After you provide the three versions, ask the learner which version they prefer. Then address the rest of the learning at the corresponding level of complexity.

2) Change the prompt to provide an interactive learning experience. Report your changes and copy/paste some of the output in an analysis of the effectiveness of an AI-learning tutor.

- *Student Observations:* Students found the AI could modify or differentiate the responses, but the information was shallow and contained too much jargon for K-12 students. Also the middle and lower levels of information were very similar. One student shared: "I just added the sentence: ask interactive questions like a conversation to the end of the prompt."
- *Example Student Response: 1) The information seems pretty accurate. It does interpret "complexity and sophistication" as language and delivery, not content. So the multi version responses leaned more towards giving surface-level information in increasingly verbose and dense language. 2) I added a quiz component to make the tutor more interactive. I think that some of the questions it came up with were very specific and difficult. That may have just been that I was testing it at the high complexity level. Occasionally, when I answered one of the quiz questions it would just regurgitate my response rather than adding other possible answers or examples. It seems to not like to tell me I'm wrong.*

Differentiating Curriculum

- *Student Instructions for AI Prompt:* Provide a LLM with a specific aspect of recursion that you would like to teach with a specific programming language. Instruct the LLM for the given concept/language 1) Develop flipped lesson activities for 3-5 different types of students. 2) Develop targeted activities to address programming misconceptions.

  Provide a copy of a) your prompt; b) a snippet of the LLM result; c) your analysis of the accuracy of the LLM; and d) suggested improvements.

- *Example Student Repsonse: a) Develop targeted activities to address the misconception of recursion infinitely looping. (Programming specific, high school level) Misconception: Recursion is infinitely looping Activity: Recursive Storytelling Objective: To explain recursion, emphasizing the base case as the mechanism that prevents infinite loops. Description: Start a story that requires going deeper into sub-stories before resolving the previous layer (similar to nested Russian dolls). Assign roles to students for different parts of the story, ensuring each sub-story has a clear end (base case) before moving back up. This narrative approach helps demystify recursion by illustrating how recursive calls progress deeper before unwinding back to the start, all controlled by base cases. c) I really liked this response from the LLM. I wish it was longer, and it wasn't completely accurate in the sense that it only gave me one activity when I asked for activities plural. It also didn't go into much depth for the question, and the activity isn't fully fleshed out. I do however*

think it is a good hook and can easily be added into a lesson plan which students would enjoy. d) I would create an assessment in the form of a closing ticket to have the students identify the base case within 3 recursive functions. As well as give them the opportunity to ask any clarifying questions.

Personalizing Student Learning Prompts

- *Student Instructions for AI Prompt:* 1. Add a summary and evaluation of how any LLM provided a personalized application of recursion based on a topic of your interest. 2. Would you recommend this AI activity for CS HS students? If so, which students and why? 3. What would be an extension activity for students learning about recursion related to say, music, that could help students share what they learned in class?
- *Example Student Response: 1. My prompt was Please assume that you are teaching a high school student who really loves basketball and other sports. Your goal is to teach this student about recursion in computer science. In response, ChatGPT suggested the idea of passing the ball up the court in basketball as the recursive step and reaching the basket and shooting as the base case. Another way it put the idea was the player with the highest number passing to the next student until you are close enough to the basket to shoot. It also gave a strong definition and example for recursion without using the basketball analogy. 2. I think this idea could somewhat help students who are into basketball (and other sports) understand recursion. My main concern is that what is being described sounds easier to do with a while loop and is probably the better choice. The concept of moving the ball up the court (or field) could be a good way to get the idea to the students but I don't know if it is any better than similar but more apt analogies. 3. An extension activity for students learning about recursion related to music could be recursively defining how you would play all of the keys on a keyboard or all the strings on a guitar.*

Discussion & Conclusion

The review of course syllabi showed inconsistent GenAI policies across Teach@Mines courses. Although the inconsistent policies might confuse students, a survey at Mines found that around 59% of students agree that each instructor should select a GenAI policy that is best for each class. However, Teach@Mines could improve its GenAI instruction by acknowledging GenAI in all courses and ensuring that students are aware of any possible differences in policies between courses (e.g., discussing the GenAI policy on the first day of class).

CS-focused courses had AI-specific learning objectives, whereas science-focused courses did not. The CS QHL-inspired teaching prompts could be modified for all STEM pre-service courses. Future work would be to pilot distinct curricular development and instructional activity prompts in engineering.

The science teaching techniques course included purposeful assignments that required students to thoughtfully engage with GenAI tools and examine how accurate the tool is with regard to known science content. These assignments could be updated to prompt students to examine GenAI outputs for concerns beyond content accuracy. For example, students could be instructed to review the outputs for possible bias and discrimination [19].

Given GenAI's connections to CS, it was expected that most of Teach@Mines' GenAI education occurred in CS teaching courses. Teach@Mines can apply the CS- QHL-inspired prompts to the science and math teaching courses to better prepare pre-service teachers from non-CS disciplines to engage with GenAI. This follows state-level recommendations to provide AI literacy training to teachers and to test AI tools to allow for flexibility and adjustment as GenAI tools continue to evolve [20]. Pre-service teachers are primed to enter a career where AI tools are unavoidable; Teach@Mines is working to support future teachers and give them the best preparation possible to use and provide informed education about GenAI tools.

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