Applications of Artificial Intelligence Technologies in the STEM Classroom

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ABSTRACT

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The recent innovations in generative artificial intelligence technologies have raised questions on proper implementation of these programs in the classroom. Of primary concern for educators are the questions of academic integrity and how students and teachers can employ AI technologies without compromising the learning process. In this capstone project, we have conducted a review of the current literature discussing methods and practices to integrate AI programs such as ChatGPT, Google Gemini, Mircorsoft Copilot, smart tutors, chat bots, and more in science classrooms. With this review, we have developed a curriculum to familiarize pre-service teachers with strategies and resources to better utilize artificial intelligence in their future classrooms. We have found that these AI programs can be effective in the creation and organization of educational materials, as well as in helping increase student engagement and understanding of scientific principles and practices. Additionally, we have found that resources such as chat bots and smart tutors may have some efficacy in aiding students in the learning process.

Keywords: Artificial Intelligence, AI, ChatGPT, Google Bard, smart tutor, chatbot, STEM, teaching, education, classroom resources

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Contents

Chapter 1

Introduction

As we explore the potential benefits of artificial intelligence (AI) in the classroom setting, it is important to understand the context wherein the project was conducted. In this section, we briefly discuss some background information and the motivation behind this capstone project.

1.1 Background

Artificial intelligence is currently a popular topic in the STEM and educational communities. Generative AI programs such as ChatGPT, AlphaCode, Google Gemini, and others have proven themselves to be powerful tools capable of creating art, writing essays, generating code, and more. AI has also proven to be a controversial topic in the education space, as educators raise concerns about cheating, plagiarism, and other ethical issues that artificial intelligence highlights [1]. Educator's lack of familiarity with the capabilities of generative AI, along with ethical concerns over academic integrity have proven themselves as critical setbacks to wider implementation and utilization of artificial intelligence in fields that could greatly benefit from its applications [2] [1] [3].

There are many in the education space who recognize the vast potential of artificial intelligence for both teachers and students alike. Celik writes "the affordances of artificial intelligence (AI) have

not been totally utilized in education." [2]. Grant Cooper wrote, "generative AI is already having far-reaching implications for science educators" but also states that there are many questions yet to be answered concerning AI and there is much room for improvement for these technologies [4]. Others have begun to explore various applications of artificial intelligence in the STEM classroom. Large-language models (LLMs) in particular can be employed to facilitate teaching and learning. As advances in generative AI and large-language models increase their capabilities, it is apparent that these technologies can have a major positive impact in education.

1.2 Project Motivation

For my capstone project, I aim to use the findings of these papers to design an AI-focused curriculum for pre-service teachers. This curriculum will serve to familiarize educators with the current state of generative AI and will hopefully provide them with resources to successfully implement these technologies in their classrooms. Our aim is to implement this curriculum into a course on technology in teaching taught at a private university in the Western United States. Additionally, we aim to create a tool set and framework for submission to academic journals with the goal to help current and future educators feel more confident in taking advantage of these recent developments in AI technologies in their classrooms.

Chapter 2

Literature Review

There have been many publications in recent years treating the state of Artificial Intelligence technologies and their potential uses in a classroom setting. Much has been written concerning the potential uses of AI in generating course content, evaluating and grading essays and assignments, answering science questions, translating presentations and assignment instructions, and tutoring students in various fields of study [5] [6] [7]. In this review, I will discuss the results and findings of literature that treats the effectiveness of the many potential applications of generative AI in classrooms. These works were instrumental in the creation of the AI teaching curriculum created as part of my capstone project.

Additionally, a review of literature concerning situated learning and constructivism learning theories is included. These theories together constituted the framework wherein the AI teaching curriculum was written. These theories served as guide to develop the curriculum to better help pre-service teachers understand what role artificial intelligence programs can play in their future classrooms.

2.1 Classroom Applications

The potential applications of generative AI programs for teachers are numerous. By familiarizing themselves with the capabilities of LLMs, teachers stand to gain a powerful resource in helping them organize classroom content, prepare in-class activities, promote student engagement and more [2].

One helpful way teachers can use LLMs is by employing programs such as ChatGPT or Google Bard to help write course materials. In Cooper's article, he gives ChatGPT several prompts to create specific teaching unit outlines, grading rubrics, and multiple-choice quiz questions. Of the results of these prompts, Cooper writes, "ChatGPT can be helpful to generate ideas when designing science units, rubrics, and quizzes." However, he did recognize some of the faults of the LLM, claiming that some of the responses lacked clarity and were "in need of further refinement." Of this application, Cooper concludes "educators need to critically evaluate any resources and adapt it to their specific context. Teacher's expertise, experience, and understanding of their students remain key to making sound pedagogical decisions. AI does not replace the expertise of the science teacher (yet)." [4] Much of the literature discussing the use of AI to create course content agrees with this sentiment [2] [8]. Drs. Corp and Revelle claim in their study that student teachers should practice prompt-engineering in creating lesson materials and that they should evaluate the content created by ChatGPT [3].

The usage of generative AI as smart tutors or as educational chatbots is another common suggestion for use in the classroom [5] [8] [6] [9] [10]. Alam discusses the work done in creating robotic smart tutors and educators and claims, "recent advances in artificial intelligence technology are enabling the development of increasingly complex robots that act like humans. Intelligent humanized tutoring robots will thus immensely benefit education and teaching in future." [5] Similarly, Fitria discusses the capability of generative AI to teach "personalized content" to students, allowing for wider understanding of material. Fitria also found that LLMs' pattern recognition will

allow "AI [to] learn to optimize the way users learn so that the learning process can be better and more effective." [6]

A study conducted by Yin, Goh, Yang, and Xiaobin found that students in a basic computer course taught by chatbots in micro-learning groups performed similarly to their peers who received traditional instruction. They discussed how chatbot-based micro-learning also motivated students to learn independently [9]. A similar study investigated the potential of chatbot instruction in higher education. This study found that the use of chatbots increased student engagement and that the programs were effective in teaching basic concepts and providing student feedback. However, they also found that the chatbots capabilities were at times limited, especially when it came to assessing students' responses to open-ended questions and the chatbot's ability to have in-depth discussions about a given topic [10]. Other studies have identified potential areas of ethical concern including privacy, fairness, educational integrity, and sustainability of AI in its current state [10] [11]. The literature tends to agree that AI programs can be a great resource in the learning process, but that the technology requires supervision and improvement [3].

There are many other works that discuss the potential applications for generative AI in the classroom. Fitria's study finds that AI programs can be used for presentation translations, creation of educational games, quiz and test assessment, and more [6]. Kortemeyer finds that GPT-4 does have some use in grading physics assignments and solutions, but states that for high-stakes and summative scenarios, it is best used to sort various approaches, not necessarily for assigning a score [7]. Alam's article discusses the potential AI has for evaluating teachers, creating virtual learning environments, and more [5]. It is apparent that the recent innovations in AI technologies have vast potential in aiding the teaching and learning process.

2.2 Constructivism

Two educational theories had the most influence in the creation of the AI curriculum for this capstone project. The first of these is constructivism. Constructivism teaches that the learning process is not a passive one. Each individual learns by "constructing" knowledge through interactions with the learning environment [12]. Constructivism teaches that no learning happens out of context, that each individual must construct meaning through experiences to gain understanding. Hein details several principles of learning according to constructivist theory [13]:

1. Learning is an active process where the student takes sensory input and constructs meaning from it.
2. Learning involves constructing meaning and constructing systems of meaning.
3. The action of learning is mental
4. Learning involves language
5. Learning is a social activity
6. Learning is contextual
7. One needs knowledge to learn
8. It takes time to learn
9. Motivation is key to learning

It is with these principles in mind that we created the curriculum and activities to familiarize preservice teachers with the potential uses of AI in their classrooms.

2.3 Situated Learning

Situated learning is another learning framework that guided our creation of the curriculum. Situated learning suggests that understanding occurs and is influenced by the context wherein it is gained. Brown et al. write, "the activity in which knowledge is developed and deployed [...] is not separable from or ancillary to learning and cognition. [...] Rather, it is an integral part of what is learned." [14] Situated learning theory argues that the greater context wherein information is learned may be just as important as the information itself. Brown compares knowledge to physical tools, explaining that it is quite possible to own a tool and not know how to use it. However, "people who use tools actively rather than just acquire them [...] build an increasingly rich implicit understanding of the world in which they use the tools and of the tools themselves." [14]

Korthagen's article discusses situated learning in the context of educating student teachers. Korthagen writes, "most fundamental to this approach [...] is the organization of sufficient, suitable, and realistic experiences tailored to the needs and concerns of student teachers." Korthagen suggests, "learning outcomes are socially constructed" [15]. In creating our curriculum, we kept in mind the environment and context wherein we will be teaching. By designing the lessons and activities in the context of situated learning and constructivism, we believe that our educational efforts will result in effective learning and experiences for our preservice teachers.

Chapter 3

Methods

In this section, we present the context wherein the AI curriculum was piloted. We also discuss how the curriculum was designed and in what way the principles of contructivist and situated learning theories impacted the design of the lessons and activities. Additionally, we discuss the collection and evaluation of data and the limitations of this study.

3.1 Participants and Course Settings

The curriculum we designed was piloted over eight 90-minute class periods in an undergraduate course at a private university in the western United States. The participants consisted of five senior undergraduate students working towards physics, physics education, and chemistry education degrees. The purpose of the course is to familiarize pre-service teachers with recent developments in technologies such as 3D printing and artificial intelligence programs that may be applicable in their future science classrooms.

Week 1	Week 2	Week 3	Week 4
Student Plays	Unit and Lesson Outlines	Data Set Generation and Analysis	Lesson Plan Project 2
Classroom Chatbots	Exam and Rubric Generation	Lesson Plan Project 1	Pilot Lesson Plans

Figure 3.1 AI Unit Schedule

3.2 Curriculum Design

In designing the curriculum, two deliverables were created. First, lesson plans were outlines detailing the learning outcomes and goals for each class period, as well as an explanation of the day's activities. Second, in-class handouts were created and handed out for the students to complete during class. Below is a schedule of the topics and activities planned over the course of the eight class periods.

Each class period focused on a different way teachers can utilize artificial intelligence programs in their classrooms. Each day also included an activity for students to experiment with an AI program of their choice and share their results with the class. At the end of the unit, the pre-service teachers were tasked with using artificial intelligence to create fully detailed and specific lesson plans, use what they have learned about prompt engineering to refine the results, and then pilot those lessons in class with their classmates as students.

Each of these in-class activities and handouts were designed within the framework of constructivism and situated learning theories discussed in the literature review. Each handout includes a pre-class question to get an idea of the students' preconceived notions and understandings of the topic being discussed. This is congruent with contructivist learning theory as it allows the educators to understand and establish the context in which the material will be taught. Additionally, each lesson includes time for the students to participate in the creation of some product using AI

technologies. These activities are designed to help students "construct" their understanding of current AI capabilities and functions, as well as potential shortcomings [13]. Furthermore, this practice is in line with situated learning theory as it both provides the tools of learning and the context wherein these tools may be of most use [14]. By incorporating principles of learning theory, we anticipate the curriculum to be effective in the classroom.

3.3 Data Collection and Evaluation

The data from this project was collected via student responses on handouts given in class. These handouts included questions for the students to answer before the in-class activity, instructions for the day's activity, and multiple open-ended questions to facilitate discussion and gather feedback from the students about the activity. Further data was collected through an end-of-course survey.

Responses were evaluated in the framework of grounded theory. In accordance with grounded theory, we approached the data without any preconceived frameworks or categories for the responses. Instead, we allowed similarities in responses and themes of the students' answers to guide our development of codes. As such, open-coding methods were used to organize responses and identify common themes and trends in the feedback.

3.4 Limitations

The primary limitation of this study is the small sample size of participants that were not randomly selected or controlled. Due to these limiting factors, we cannot make generalized claims that are true for the larger body of pre-service teachers and educators. However, this smaller sample size allows us to make cases that may be applied to people in simliar situations.

Chapter 4

Results and Conclusion

During the collection and analysis of the students' responses, certain common elements and themes stood out about their perspectives on AI and how they plan to implement the use of these technologies in their future classrooms. In this section, we discuss the day-by-day objectives and the students' feedback during the AI unit. Furthermore, lesson plans developed by students using AI tools are included, along with a discussion of these results. All proper names mentioned are pseudonyms.

4.1 Feedback and Curriculum Refinement

The first day of the AI curriculum served as an introductory lesson to the content of the unit and to give an example of how AI can encourage student engagement in science classrooms. Before the activity, the students were asked what role they expected AI to play in their teaching career. All students indicated that they expected to use AI in some capacity to simplify tasks such as grading or lesson planning (Day1_Handouts). Two students expressed concern over students using generative AI to cheat or take shortcuts in their schoolwork (Theo_Day1_Handout)(Jacob_Day1_Handout).

The in-class activity for day one involved the students breaking up into groups and using an LLM to write a script for an educational play as a method of increasing student engagement with

educational material. The students were given some topic ideas as well as some guidance on prompt engineering. The students were instructed to evaluate how effective the AI program performed and how accurate the responses were. From the responses, two students mentioned that the "AI is prone to errors" (Jacob_Day1_Handouts) or that the information they received was factually incorrect. One of these students mentioned that this could be useful as an exercise for students to look for and correct errors (Edith_Day1_Handouts). When asked about how effective they expected this activity to be in their classrooms, two students indicated that the use of generative AI in this context would be more effective if the students were already somewhat familiar with the content (Edith_Day1_Handouts)(Jacob_Day1_Handouts).

The second day of the AI curriculum had the students practice creating GPT-powered chatbots. Students were given directions for how to provide material for the chatbot to reference and were asked to evaluate how well the AI answered questions clearly and accurately. One student indicated that the AI-powered chatbot was "pretty accurate" to the source material provided. This same student even experimented with instructing the AI to respond in specific ways, such as to be rude to the user as it answered questions. The student found that the chatbot followed these directions, making for a more personalized experience (Justin_Day2_Handouts). When asked, all students indicated that they did not believe AI would be capable of replacing the role of a live teacher any time soon (Day2_Handouts).

Day three of the AI unit covered the generation of unit and lesson outlines using LLMs. The students were asked to identify a specific unit of any course for an age/grade level of their choosing. They were tasked with using an LLM of their choice to generate a unit-level outline and lesson outlines to teach the topic to the age level they indicated. One student indicated some difficulty in getting the AI to adjust the lessons for the appropriate age level (Jacob_Day3_Handouts). However, most students found this method of employing AI to be useful. One student stated that they "see [AI] as a way to save myself a lot of time with general lesson designs, giving me more time

to fine-tune them for my students" (Nick_Day3_Handouts). Two other students mentioned that this activity would be helpful to generate content ideas and to better organize course materials (Edith_Day3_Handouts)(Justin_Day3_Handouts). All students indicated that these unit and lesson outlines were helpful, but would need adjustment before employment in an actual classroom (Day3_Handouts).

Day four saw the students use AI programs to generate exam questions and grading rubrics for free-response questions. The students were tasked with using an LLM to write multiple-choice and free-response questions on a topic of their choosing for a specific grade level of their choice. They were also instructed to generate a rubric to assess the free-response answers. All students agreed that the AI program did well to generate questions, but that the multiple-choice options need to be reviewed by a teacher before use (Day4_Handouts). Two students indicated that AI is better suited for the generation of conceptual-type questions rather than math or algebra-based questions (Edith_Day4_Handouts)(Nick_Day4_Handouts). As far as rubric generation, one student claims that they expect AI to be "just as good as I would be at making one" (Justin_Day4_Handouts). Two students responded that initial results had some flaws or inaccuracies, but with adjustment and prompt engineering they were able to get the LLM to recognize and correct the errors (Jacob_Day4_Handouts)(Justin_Day4_Handouts).

The fifth day involved the students using generative AI programs to create and analyze sets of scientific data. In this lesson, the students were tasked with generating data sets for a scientific measurement or experiment of their choosing, and evaluate whether the data sets the AI generated were realistic and useful. They were also asked to test how well AI programs could analyze real data sets. In this activity, one student noted that Microsoft's Copilot was more effective than ChatGPT in creating realistic and useful sets of data (Justin_Day5_Handouts). Another student mentioned that ChatGPT was adept at creating graphs from given data and was able to find mathematical relationships within a set of data (Jacob_Day5_Handouts).

4.2 Lessons using AI Tools in Science

The last three days of the AI unit were dedicated towards a student project to create and pilot in-depth lesson plans using AI tools to teach scientific concepts. In this project, the pre-service teachers came up with interesting ways to use AI as a tool in helping students learn and become confident in the various topics they chose.

One student, Justin, designed a lesson to help students review what they have learned at the end of a unit. This lesson plan has students instruct an AI to pretend not to know anything about the topic. The students are then tasked with "teaching" the AI what they have learned about in the unit preceeding this lesson. After the students feel confident that they have explained all the concepts, a multiple-choice test is given to the AI with instructions to provide answers based only on the chat history between the AI and students. The students then have the chance to evaluate their own understanding and how well they passed that understanding on to the LLM (Justin_LessonPlan).

Another student's lesson involves students using AI programs to come up with experiments to learn about a topic. In this lesson, the students are tasked with coming up with a scientific model and using an LLM to come up with an experimental design to test the validity of their model (Jacob_LessonPlan).

Three students, Nick, Edith, and Theo, created lesson plans related to the day five data set activity. One of these lessons involves conducting an experiment and taking data of melting and boiling points of substances, then using generative AI to create a set of pseudo-data for the same experiment. The students are then tasked with analyzing the data from the AI program and determining whether or not the data is realistic (Theo_LessonPlan). Another pre-service teacher's lesson involves the students taking measurements and data, analyzing it themselves for trends and patterns, then feeding the data to an AI program to see what patterns the AI might catch that the students missed. The students are also instructed to ask the AI about the process it undergoes to analyze data. They are then asked about the similarities and differences of their approach to data and the AI's approach

(Nick_LessonPlan). The last lesson involving data sets has students pull data from the official NASA website and feed it to a generative AI. The students are then instructed to use the AI program to generate plots and identify trends in the data. The students then discuss and share their findings with the class (Edith_LessonPlan).

4.3 Discussion

Our results explore the potential uses of AI and LLMs in STEM classrooms. As discussed in the literature review, AI has many potential applications for the educational field. One of these applications mentioned is the ability of LLMs to write course materials [4]. According to our results, AI has shown itself to be effective in the creation and organization of unit and lesson outlines and in the generation of test questions and grading rubrics. However, we agree with the findings of others that these products should be evaluated and adjusted by teachers before use [4] [3].

Furthermore, our study of the effectiveness of AI chatbots and tutors has shown that these may be effective methods in helping students learn material and engage with content. The pre-service teachers in our studies found that these chatbots were particularly effective when fed specific information on the course from textbooks or similar resources. Our results show that the current state of chatbots has a lot of potential, but we also agree with the findings of others that this technology requires supervision and improvement [3].

Our results lead us to conclude that the current state of AI programs can have major benefits for educators in STEM classrooms. From creating lesson plans and test questions to generating or analyzing sample data sets, this technology can help teachers more effectively engage and teach students. We recognize, too, that generative AI and LLMs are far from perfect, and, while they can be effective tools, teachers need to evaluate the effectiveness and accuracy of these programs in their classes.

Appendix A

Lesson Plan and Handout Samples

Day 1 Intro: Student Plays

Learning Objective: Give students ideas for how artificial intelligence can be used for classroom activities to promote engagement and learning. Introduce students to prompt engineering.

Unit-Level Essential Question: What potential benefits might AI have in my classroom? How can I implement AI into my teaching?

Lesson-Specific Essential Question: How can I use a large-language model (such as ChatGPT, Google Gemini) to learn scientific concepts through text generation? I.e. plays, stories, etc.

Materials:

- Preclass question (handout)
- Preclass reading assignment
- In-class handout (below)

Breakdown:

Time	Teacher	Student
15 min	Introduction / Activity Instructions	Listening / Note taking
30 min	Roam classroom, help students improve scripts through prompt engineering, answer questions	Begin play generation, prompt engineering, rehearse plays
20 min	Evaluate plays	Perform plays
15 min	Facilitate discussion	Discuss efficacy of prompts, accuracy of science content, effectiveness in engaging students, etc.

Artificial Intelligence 1: Student Plays

Pre-class Question: What role do you expect Artificial Intelligence to play in your teaching career? Why?

Activity: In groups, use a large language model (LLM) such as ChatGPT or Google Gemini to generate a script for a play that teaches some basic scientific principle through the story. The plays should be about 5-8 minutes long, and avoid "teacher-student" style plays (where one character is explicitly teaching another). Use what you know about prompt engineering to refine the AI's response into an accurate and interesting short play. Rehearse the script with your group, and perform your play for the class.

Topic Ideas:

- Ohm's Law
- Physical and Chemical Reactions
- Water Cycle
- 3-Body Problem
- Photosynthesis
- Newton's Laws

Prompt Engineering Ideas:

- Try telling the LLM to write the play in a specific setting (fantasy, sci-fi, etc.)
- Try asking the LLM to write in a specific genre (tragedy, comedy, etc.)
- Identify factual errors or mistakes in the script and write follow-up prompts instructing the LLM to correct the errors

Discussion:
How well were you able to get what you wanted from the LLM on the first try? What did you change to get better results?

Did you get any incorrect content from the LLM? Give some examples. Were you able to get the AI program to recognize and correct the mistake?

How effective do you believe this activity would be in engaging students in the learning process? What changes might you make if you were to implement a similar activity in your classroom?

Day 4 Teacher Strategies: Exam and Rubric Generation

Learning Objective: Understand how effectively LLMs can write test questions and grading rubrics.

Essential Question: How well can LLMs create relevant and accurate test questions and grading rubrics?

Materials:

- Pre-class reading assignment
- In-class handout

Breakdown:

Time	Teacher	Student
15 min	Introduction / Activity Instructions	Listening / Note taking
25 min	Roam classroom, help students improve responses. Give topic ideas for test questions	Create test/quiz questions with answers. Evaluate accuracy and quality of questions and answers
25 min	Roam classrooms, assist students	Create grading rubrics. Evaluate quality of responses
15 min	Facilitate discussion	Discuss efficacy of prompts, accuracy of science content, etc.

Handout Ideas:

- Have students identify what content they will generate test questions for
- Have students identify the grade level the questions will be assessing
- 5 multiple choice questions, 2-3 open-ended questions
- Assessment criteria:
    - How accurate are questions?
    - Are questions grade-level appropriate?
    - What order of Bloom's Taxonomy does the question fall under?
- Build their quizzes in Google Forms, submit a link to Dr. Bennion in Learning Suite (maybe email?)

Artificial Intelligence 4: Exams and Rubrics

Pre-class Questions: How well do you think artificial intelligence programs can write exam questions that are on topic, at an appropriate grade level, and accurate?

How well do you expect LLMs to generate rubrics for grading short answer or free-response type questions? Why?

Activity: Identify a topic and a target grade level to test on. Using any LLM (ChatGPT, Google Gemini, Microsoft Copilot, etc.) generate 5 multiple-choice questions and 2-3 short answer questions on the topic that are appropriate for the chosen grade level. Assess the quality of the LLM's response using the following criteria:

- Are the questions accurate?
- Are the questions grade-level appropriate?
- What order of Bloom's Taxonomy do the questions fall under?

Use what you know about prompt engineering to refine your results until they are satisfactory. Then, build your exams in Google Forms and submit a link to Dr. Bennion.

Discussion:
How well were you able to get questions that were both accurate and appropriate for the target grade level?

What order of Bloom's Taxonomy did the questions fall under? Did the LLM tend to give multiple questions of the same order, or did it provide a variety of questions?

Did you get any incorrect content from the LLM? Give some examples. Were you able to get the AI program to recognize and correct the mistake?

How do you plan on using artificial intelligence to generate test questions and grading rubrics?

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