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Generative AI pedagogical agent as learners' inquiry assistant: Designing and implementing Situational Teaching

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Abstract: The rapid adoption of GenAI is deeply reshaping education, enriching the educational scenarios and providing the new approach for innovative teaching designing and personalized learning. However, in traditional science education, the learning scenarios are disconnected from the real inquiry situation, which makes it difficult to enhance students' interest and scientific inquiry skills. This study designed the GenAI pedagogical agent and constructed a GenAI-empowered situational teaching model to improve high school students' scientific inquiry skills. The study was conducted under two separate experiments through a quasi-experimental approach. Results revealed that the model was effective in promoting students' scientific inquiry skills and showed significant progress in all steps of scientific inquiry. In addition, the results showed that the teaching model can significantly stimulate students' interest in learning. Surprisingly, it was found that GenAI may produce content illusion and students' over-reliance on GenAI. We discussed the implications of the findings and recommended it to educators seeking to prepare students for the challenges Higher-order Thinking Skills.

Keywords: GenAI, scientific inquiry skills, pedagogical agent, situational teaching

1. Introduction

Scientific literacy drives societal progress and human advancement. The PISA 2025 framework prioritizes students' abilities to identify research questions, design investigations, and critically analyze data – aligning with global science education standards (White, 2023; Pumfrey, 1991; NRC, 1996; Milford et al., 2010). While students should explore real-world phenomena like scientists, abstract textbook content often diminishes engagement and understanding (Herrington & Oliver, 2000). To address this, situational teaching helps students grasp concepts through meaningful scenarios (Papalazarou et al., 2024). Generative AI (GenAI) now offers new tools: its interactive, adaptive nature enables personalized learning environments, real-time support, and tailored guidance to deepen scientific inquiry (Casheeka et al., 2024). However, existing research focuses primarily on GenAI's basic functions, lacking classroom-ready models or empirical studies on using GenAI-enhanced contextual teaching to develop these crucial skills. This study therefore aims to build and test a GenAI-powered contextual teaching model specifically for cultivating scientific inquiry skills among Chinese high school students.

2. Model Construction and Activity Design

The GenAI-empowered situational teaching model proposed in this study for the cultivation of high school students' scientific inquiry skills is guided by the theory of situational cognition and learning, and builds an authentic and immersive scientific inquiry context. Based on this, the study designs a Generative AI pedagogical agent that can support this situational teaching and learning, aiming to enhance the students' immersive experience and interest in learning in the process of scientific inquiry, and to improve their Scientific Inquiry Skills.

2.1 Theoretical Foundation

2.1.1 Flow theory

Flow theory posits that when learners become fully immersed in a situation, they become highly focused and enter an immersive state (Csikszentmihalyi & Graef, 1975). Based on this, the theory emphasizes that teachers should establish learning conditions conducive to student immersion during instruction. Therefore, when designing the instructional model, this study fully considered students' psychological needs, thus addressing the fundamental question of why learning contexts should be created in teaching.

2.1.2 Situational cognition and learning theory

Situational cognition and learning theory emphasizes that learners should construct knowledge through authentic activities within specific contexts, rather than through passive learning via abstract symbol systems (Wilson & Myers, 2000). Based on this principle, when designing the instructional model, this study carefully considers how to integrate situation creation with teaching content, thus addressing the essential question of what types of situations should be established in teaching.

2.1.3 A constructivist-based theory of technology use

Jonassen's constructivist framework proposes that information technology supports learning through five key functions: multimodal resource libraries, information tools, contextual support tools, reflective thinking scaffolds, and social mediation (Jonassen, 2003). This study fully integrates the characteristics of GenAI technology to design a situation-based teaching model for developing scientific inquiry skills, thereby addressing the critical question of how to effectively create teaching situation.

2.2 Model construction: GenAI-empowered situational teaching model for the cultivation of scientific inquiry skills （GSM for SIC）

GenAI-empowered situational teaching does not simply aim at knowledge transfer, but more importantly guides students to be able to independently explore and dis-cover problems in real-life situations, independently investigate problems using ideas and methods of scientific inquiry, and transfer and apply what they have learned from their investigations. Therefore, this study designed a GenAI-empowered situational teaching pointing to the development of scientific inquiry skills, as shown in Figure. 1. By summarizing the ideas of situational cognition and learning theory, the model proposes that situation creation should follow the principles of authenticity, interactivity, generativity, Constructiveness and Integrity. Building on Jonassen's five principles and technological framework, this study establishes GenAI integration guidelines to create authentic, active, collaborative (human-AI), constructive, and intentional learning environments. We define roles, functions, and dialogue features for GenAI learning companions to support scientific inquiry: Teachers first create authentic situations with investigable problems, where GenAI engages students to identify scientific questions. During inquiry, students—with teacher scaffolding—hypothesize, experiment, and analyze data while GenAI provides multimodal resources, personalized tutoring, and Socratic dialogue to foster knowledge construction. Finally, teachers consolidate learning and promote transfer, while GenAI evaluates the inquiry process to drive reflection. Throughout, students remain active agents constructing knowledge through scaffolded exploration to develop scientific inquiry skills.

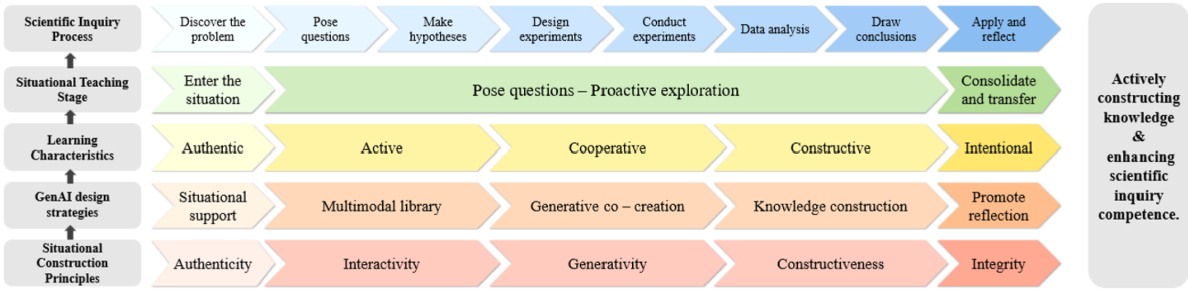

Figure 1. GenAI-empowered situational teaching model for the cultivation of scientific inquiry skills (GSM for SIC)

2.3 Activity Design: Medical Innovation in Epidemic Prevention and Control

To validate the effectiveness of the aforementioned situated instructional model, the study designed a 6-class-hour interdisciplinary scientific inquiry activity centered on the authentic, life-relevant theme of "Medical Innovations in Epidemic Prevention and Control."

3. Teaching Practices and Outcomes

3.1 Participants

The experimental subjects of this study were two classes of 74 students, 29 male and 45 female, in the first grade of a middle school in S city, China. The students had some prior but not in-depth knowledge about immunization-related issues and had been exposed to simple scientific inquiry experiments in their previous studies. Through random assignment, 37 students were assigned to the experimental group, i.e., they were taught in GSM for SIC, which points to the development of scientific inquiry competencies. 37 students were assigned to the control group, i.e., taught in the traditional teaching mode.

3.2 Research tools

3.2.1 Questionnaire

In this study, the “Scientific Inquiry Skills Questionnaire” was administered to students in the experimental group and the control group before and after the experiment. The questionnaire was adapted from Liu's (2018) “Scientific Inquiry Skills Questionnaire” and referred to the description of scientific inquiry skills in the Chinese curriculum standards (MOE, 2020) and the requirements of the PISA 2025 Scientific Literacy Framework for students' scientific inquiry skills (White, 2023). The questionnaire was divided into a total of seven dimensions of posing questions, making hypotheses, designing experiments, conducting experiments, analyzing data, drawing conclusions, and expressing and communicating with a total of 21 questions on a five-point Likert scale (1 = Strongly Disagree; 5 = Strongly Agree) with reverse questions. The scale had good reliability (Cronbach 's α of 0.95) in this study.

In this study, a learning interest questionnaire on the topic was administered to the students in the experimental group before and after the experiment. This questionnaire was adapted from PISA 2015 (OECD, 2017) regarding the description of interest in science learning based on the content of the lectures. The questionnaire consisted of 4 questions on a five-point Likert scale (1=strongly disagree; 5=strongly agree) with reverse questions. The scale had good reliability in this study (Cronbach 's α of 0.84).

3.2.2 GenAI pedagogical agent design

In this study, based on General Language Model 4, we designed and developed an intelligent learning companion, and set up roles and personalized prompts for this intelligent learning companion. Among them, the personalized prompts are developed from four aspects: roles, goals, thinking paths and personalized characteristics. In the thinking path section, add the paragraph "Use questions to guide students to deconstruct and deeply analyze the core question rather than give direct answers", in the thinking path section of the personalized prompts, emphasize "point out the next step in the thinking path in the form of a question", and in the personalization section, emphasize "heuristic guidance". In the personalized prompts' thinking path section, it emphasizes "pointing out the next thinking path in the form of a question", and in the personalized features section, it emphasizes "heuristic guidance" and promotes students' active thinking through heuristic dialogue.

3.3 Data analysis

This study used SPSS 26 software to statistically analyze the obtained data. After passing the normal distribution test, independent samples t-test was utilized to compare the differences between the pre-test scores and post-test scores of scientific inquiry skills of the experimental group and the control group. The paired-samples t-test was used to compare the differences between the pre-test and post-test scores of scientific inquiry skills and learning interest of the experimental group. The above analyses were synthesized to verify the effectiveness of the GSM for SIC.

3.4 Findings

3.4.1 Differences in scientific inquiry skills between experimental and control groups

In this study, independent samples t-tests were conducted on the pre-test scores and post-test scores of the subject students respectively. The results of the test showed that in the pre-test, there was no significant difference (t=1.857, p=0.067) between the scores of the experimental group (M=3.61, SD=0.49) and the control group's scientific inquiry skills (M=3.36, SD=0.68). In the posttest, the experimental group's scientific inquiry skills (M=4.19, SD=0.59) was significantly higher (t=2.305, p=0.012) than the control group's (M=3.89, SD=0.54) scores. It indicates that GSM for SIC can effectively enhance students' scientific inquiry skills. (see Figure 2)

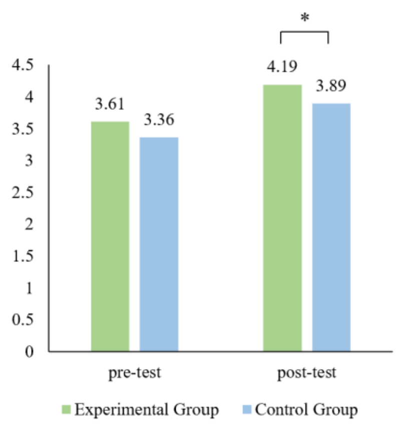

Figure 2. Differences in scientific inquiry skills between the experimental and control groups in the pre-test and post-test respectively

3.4.2 Improvement of scientific inquiry skills in the experimental group

In this study, a paired-samples t-test was conducted to examine the pre and post-test levels of scientific inquiry skills of students in the experimental group in each dimension. The results of the test show (Figure 3) that the posttest scores of the students' scientific inquiry skills in each dimension are higher than the pretest scores, indicating that GSM for SIC can effectively enhance the students' skills in all processes of scientific inquiry.

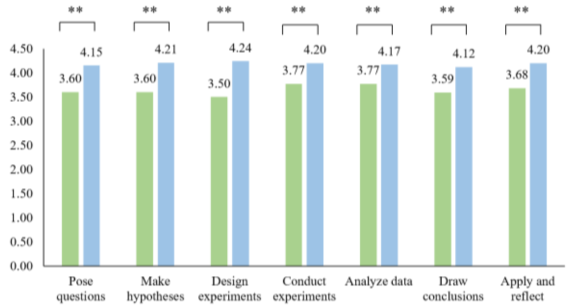

Figure 3. Differences between pretest and posttest of students' scientific inquiry ability in each dimension in the experimental group

3.4.3 Improvement of learning interest in the experimental group

In this study, a paired sample t-test was conducted on the pre-test and post-test scores of students' learning interest in the experimental group. The test results showed (Figure 4) that students' learning interest was significantly higher after the experiment (*M*=4.27, *SD*=0.67) than before the experiment (*M*=3.77, *SD*=0.74), indicating that GSM for SIC can significantly enhance students' learning interest.

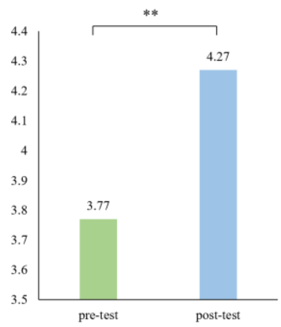

Figure 4. Differences between pre-test and post-test of students' learning interest in the experimental group

4. Conclusion and Prospect

This study makes full use of the features of GenAI, integrates it with teaching in depth, and designs and develops a GenAI pedagogical agent. Based on this, a GenAI-empowered situational teaching model for the cultivation of scientific inquiry skills was constructed, and its effectiveness was simply verified. The results show that the model can significantly improve students' scientific inquiry skills and stimulate students' learning interest.

In order to further realize the potential of GenAI in pedagogy, this study will explore the following aspects in depth:

First, in this study, GenAI pedagogical agent is integrated into the teaching de-sign as a carrier of situation, which can further stimulate students' interest in learning and keep them immersed in the inquiry situation through role-playing and other means. In this process, students maintain relative trust in GenAI. However, due to the existence of a “black box” in the generated content, AI hallucinations may occur from time to time. AI hallucinations generally manifest in two ways. First, providing incorrect answers or fabricating facts. To address this, the study implemented safeguards through knowledge base configuration. Second, failing to understand student queries and giving irrelevant responses. This may increase cognitive load, causing students to disengage from immersive learning contexts and disrupting inquiry processes. Mitigating this requires further training of the GenAI-based learning companion. Subsequently, this research will explore methods to minimize the second type of hallucination, refine the design process, and provide frontline teachers with reliable, effective strategies for integrating GenAI into situated teaching.

Second, this study verified the impact of GSM for SIC on students' scientific inquiry skills and learning interest. Although certain restrictions were imposed on the output content of GenAI in this study so that it could not tell the answers directly to students. However, in the course of the study, we still find that a few students are able to make GenAI output the answers directly through the subtle design of cue words. The convenience of GenAI is prone to induce learners to fall into the trap of cognitive outsourcing, which makes students rely too much on GenAI and leads to the weakening of cognitive level and higher-order thinking. Therefore, when integrating GenAI into instructional design, its impact on students' higher-order thinking needs to be further considered.

Acknowledgements

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