GCCCE 2025

第二十九届全球华人计算机教育应用大会

GCCCE 2025

博士生论坛论文集

Doctoral Student Forum Proceedings

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GCCCE 2025 博士生论坛论文集

GCCCE 2025 Doctoral Student Forum Proceedings

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博士生论坛 Doctoral Student Forum

一、序言 Message from the Organiser

GCCCE 2025 博士生论坛为支援计算机教育应用领域中年轻研究人才的成长，向全球华人优秀博士生提供一个与同行交流学术的平台，并在和他们研究领域相关的专家小组的引领下深入讨论问题。参与者就他们的博士论文进行协作探究以及学术讨论，从而对研究进行完善，改进以及深化对计算机教育的理解。本论坛为参与者提供了一个机会去思考他们博士论文研究和提出值得进一步调查和讨论的问题；一个与专家小组和其他博士生对话的平台，参与者可以贡献想法并且接收对他们当前的研究的回馈意见和指导；一个共同体来支援活跃在计算机教育研究领域的年轻学者。

本论文集收录了 7 篇由参与者撰写的论文，涵盖了 GCCCE 2025 其中多个主题: 学习科学与计算机支持协作学习，移动、泛在与情境化学习，悦趣化学习、教育游戏与数字玩具，高等教育与成人学习的技术应用、教师专业发展，技术增强语言与人文学科学习，人工智能教育应用、智慧学习环境，学习分析与学习评估，STEM 与创客教育，和教育技术创新、政策与实践。今年的博士生论坛包含两个部分：报告与专家研讨。在报告与讨论中, 博士生论坛得到了以下专家小组的全力支持与协助:

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我们必须再一次感谢 20 位来自中国内地、台湾、香港、澳门和新加坡的资深华人学者担任程序委员。

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GCCCE 2025 Doctoral Students Forum

Designing a GenAI Chatbot-Enhanced Blended Synchronous Learning Environment to Improve Online Learners' Emotional Engagement

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Abstract: *Blended synchronous learning (BSL) combines in-person and online instruction in real-time, enabling remote learners to join classroom activities. While BSL offers flexibility and merges the benefits of both modalities, online learners often lack emotional engagement due to limited social interaction and personalized support. To address this, this study proposes designing a GenAI chatbot using ChatGPT to enhance online learners' emotional engagement by providing social interaction and personalized support. This proposed research will follow the educational design research approach, and progress through 3-4 iterative rounds of design, implementation, and formative evaluation to gradually optimize the design of the chatbot. This study aims to fill gaps in research on generative AI for emotional engagement in BSL.*
Keywords: Blended Synchronous Learning, Engagement, Interaction, GenAI Chatbot

1. Introduction

Blended synchronous learning (BSL) is an instructional approach that integrates classroom instruction and online learning in real time, allowing remote learners to join classes via interactive technologies like video conferencing (Garrison & Vaughan, 2007). BSL offers flexible, accessible, and simultaneous learning opportunities, especially for adult learners balancing work and study (Wang & Quek, 2016). Therefore, BSL is a highly practical approach for learners, especially adult learners.

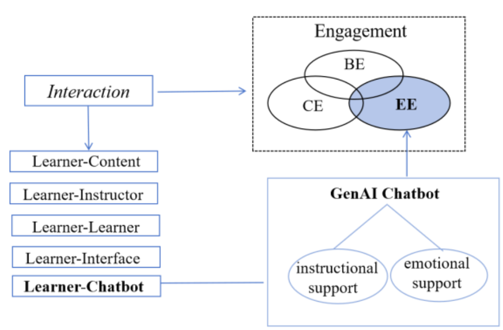
However, BSL still faces some issues, particularly low engagement among online learners, which impacts academic performance, satisfaction, and dropout rates (Fredricks et al., 2004; Wang et al., 2017). Emotional engagement, a critical factor relatively overlooked in existing research, is often hindered by isolation, lack of social interaction, and insufficient personalized support (Wang & Huang, 2023). Nevertheless, emotional engagement is less studied and remains an area needing further exploration.

This study proposes to design a GenAI-powered chatbot to enhance emotional engagement in BSL by offering real-time interaction and personalized support. Specifically, the study seeks to answer three research questions:

1) What characteristics should an interactive GenAI chatbot have for the purpose of emotionally engaging online students in the BSL environment?
2) To what extent does this GenAI chatbot enhance the emotional engagement of online learners?
3) What are learners' perceptions of the use of GenAI chatbot to emotionally engage their learning in the BSL environment?

2. Conceptual Framework

Figure 1 shows the conceptual framework that guides the design of the study. In this section, the key concepts involved in the framework and relevant research studies are reviewed.



Note.BE= behavioral engagement CE= cognitive engagement EE= emotional engagement

Figure 1. The conceptual framework

2.1. Engagement and Emotional Engagement

Engagement is a multifaceted construct described as “the holy grail of learning” (Sinatra et al., 2015), as it is closely related to academic achievement and satisfaction. In online learning, engagement is often defined as cognitive, affective, and behavioral energy learners exert when interacting with others, learning materials, and activities (Martin & Borup, 2022). Although online learning offers flexibility, it often lacks the immediacy of in-person interactions, leading to high isolation and dropout risks. Engagement is commonly categorized into three dimensions: behavioral, cognitive, and emotional (Fredricks et al., 2004). Behavioral engagement includes the learner’s attention, concentration, and curiosity to a learning task and other observable actions, and cognitive engagement emphasizes learners’ mental endeavor in learning (Fredricks et al., 2004). Emotional engagement, which this study emphasizes, refers to learners’ affective states during learning (Skinner & Belmont, 1993). The relationship among these dimensions is dynamic, overlapping, and interdependent. For instance, behavioral engagement is often seen as the physical representation of cognitive and affective engagement, while cognitive engagement predicts behavioral and emotional engagement (Martin and Borup, 2022).

Measuring emotional engagement requires monitoring learners' learning-related emotions and their dynamic changes. Traditional methods, such as self-reports, surveys, and interviews, could effectively capture emotional engagement but are retrospective and subjective, often failing to track real-time emotional changes (Schall, 2014). This study explores facial expression analysis as a non-intrusive, objective method to supplement traditional tools, enabling the real-time monitoring of emotional engagement (Schall, 2014).

Emotional engagement is categorized into two dimensions: positive (POS) and negative (NEG) (Wang et al., 2015). POS, which involves positive emotions like joy and confidence, has a positive correlation with academic performance. In contrast, NEG involves emotions like boredom, frustration, and anxiety, which are common in technology-mediated learning and often hinder learning outcomes. Providing social support and interaction often helps in decreasing the NEG and fostering the POS. Therefore, this study will design and implement a GenAI chatbot to provide real-time instructional and emotional support for online learners in a BSLE, aiming to enhance learners' POS.

2.2. Interaction

Moore (1989) identifies three forms of interaction in distance learning: learner-content, learner-instructor, and learner-learner. Hillman et al. (1994) expand Moore’s framework by adding learner-interface interaction, which addresses how learners interact with technology during the learning process. More recently, the emergence of AI technology has introduced an additional form: learner-chatbot interaction. Empirical studies have demonstrated the potential of educational chatbots to enhance learning accessibility and engagement (Okonkwo & Ade-Ibijola, 2021). Kuhail (2022) conducted a systematic review highlighting chatbots' ability to improve learner engagement, analyzing their roles and interaction styles. However, the potential of generative AI (GenAI)-based chatbots, like ChatGPT, remains unexplored in online or blended learning environments (Kuhail, 2022). This study seeks to fill the gap by designing a GenAI chatbot to enhance existing interaction types in a blended synchronous learning (BSL) setting, providing online learners with timely responses and emotional support to improve learner emotional engagement.

2.3. GenAI in BSL and Engagement Studies

GenAI can generate meaningful content such as text, images, and audio based on training data (Feuerriegel et al., 2024). ChatGPT, a representative GenAI chatbot, was launched by OpenAI in November 2022 (Rahman & Watanobe, 2023). Unlike non-GenAI chatbots, ChatGPT recalls previous conversation parts, enabling coherent dialogue. A key feature of ChatGPT is its ability to process natural language queries, enabling learners to interact with it as they would with instructors (Rahman & Watanobe, 2023). Educational chatbots are designed specifically for teaching and learning. Advances in Large Language Models (LLMs) have enabled intelligent chatbots to offer personalized, interactive, and affordable guidance, and these tools could answer students' questions, provide feedback, and facilitate collaboration between learners and the instructors. In blended learning studies, Alshahrani (2023) identifies their ability of GenAI chatbots to provide personalized feedback and enhance sustainable blended learning environments, while also calling for empirical research on their impact on motivation and engagement. Furthermore, in a systematic review, Lo et al. (2024) analyze 72 studies on ChatGPT’s impact, noting that emotional engagement remains underexplored. In this proposed study, the chatbot will play the teaching agent and motivational agent (Kuhail,2022). There are two interaction mechanisms between the chatbot and the learner:1) The learner actively initiates a conversation by asking the chatbot instructional questions related to the lecture. The chatbot responds with relevant explanations and provides emotional support; 2) When the system detects that the learner is experiencing a low level of emotional engagement, it proactively activates the chatbot. The chatbot then initiates a simple inquiry to prompt the learner to ask questions or offers emotional encouragement.

3. Research Design

3.1. Context and Participants

This study will be conducted with adult learners, who are taking higher degree courses at a Singaporean university. In each course, the number of participants is around 20. There will be 13 weeks of teaching sessions per semester, and each session is about 2-3 hours. 6-8 weeks of sessions will be conducted in the BSL mode.

3.2. Method (Educational Design Research)

This study will follow the educational design research approach. It is a systematic method that addresses complex educational problems and achieves deeper theoretical and practical knowledge by designing, developing, and implementing innovative educational interventions in authentic contexts (Plomp, 2013). This method fits this study well because integrating a GenAI chatbot in a BSL setting is a relatively new attempt, and little experience is available in existing studies. Therefore, this study will go through several iterations based on formative evaluation and reflection before an optimal solution is reached. More specifically, this study will involve preliminary research, prototyping, and assessment stages (Wang et al., 2017), as shown in Figure 2.

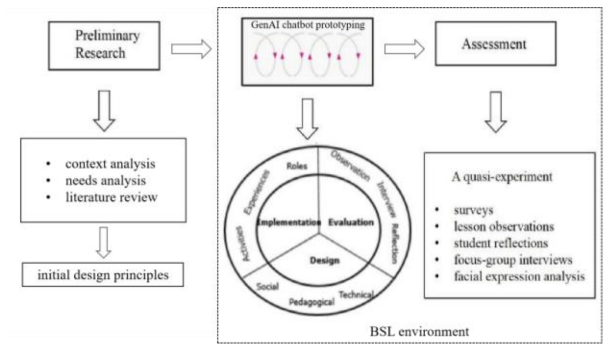


Figure 2. The process of designing and assessing the GenAI chatbot in the BSL environment

In the preliminary research stage, initial design principles will be proposed after context analysis, needs analysis, and literature review. The actual design, implementation, and formative evaluation of a GenAI chatbot in an authentic BSL environment will occur in the prototyping stage. The specific design of the chatbot will focus on pedagogical, social, and technical design perspectives (Wang et al., 2017). The design will be tested and improved in 3-4 rounds of iterations and end up with an assessment stage.

4. Assessment

During the assessment stage, a class using the GenAI chatbot will serve as an experimental group, and the other class with the same student profiles will be selected as the control group. The same instructor will teach the two classes on different days. It is going to be a quasi-experiment. The assessment will examine 1) if integrating a GenAI chatbot can enhance online learners' emotional engagement in the BSLE, and 2) what characteristics an interactive GenAI chatbot should have for emotionally engaging students, and 3) the students' attitudes and perceptions towards the design. Multimodal data, including facial expressions, lesson observations, surveys, interviews, and student observations, will be collected and analyzed during the prototyping and assessment stage.

5. Concluding Remarks

This paper presents our thoughts about utilizing a GenAI chatbot to emotionally engage online students in BSL. The study is currently at the proposal stage and detailed design and implementation has not yet been undertaken. The purpose of this paper is to share our current idea and collect feedback from other researchers and practitioners. We hope this proposal will inspire rigorous research and discussion, offering fresh perspectives and innovative suggestions to improve learner emotional engagement in BSL.

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Design Thinking in Developing Primary School Students' Computational Thinking

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Abstract: *As a high-level thinking ability, computational thinking is closely related to students' problem solving and learning outcomes, and is also an important part of STEM education. However, learning computational thinking is difficult. This study introduces design thinking into teaching methods in the hope of helping students improve their computational thinking ability. Thirty primary school students participated in STEM learning embedded with design thinking, and participated in the evaluation of computational thinking ability before and after learning. The study found that there were significant differences in students' computational thinking. However, there was no gender difference.*
Keywords: Computational Thinking, Design Thinking, STEM Education.

1. Introduction

In recent years, rapid technological advancements have transformed various aspects of our daily lives, creating a growing demand for skills related to science, technology, engineering, and mathematics (STEM). As we navigate a world increasingly driven by data and digital technologies, computational thinking has emerged as a critical skill necessary for problem-solving and innovation (Doleck et al., 2017). Computational thinking involves breaking down complex problems into manageable parts, recognizing patterns, and developing algorithms to find solutions (Shute et al., 2017).

Integrating computational thinking into STEM education is essential as it equips students with the tools to understand and engage with technology, fostering not only their analytical skills but also their creativity and collaboration abilities. By cultivating these competencies, STEM education aims to prepare students for future careers in a technology-centric labor market, ensuring they are not only consumers of technology but also creators and innovators.

Design thinking as a pedagogy can promote computational thinking by emphasizing student-centered learning and active participation, which stimulates curiosity and creativity. It focuses on solving complex, real-world problems, encourages interdisciplinary learning, fosters teamwork, and supports critical thinking through an iterative process of feedback and revision.

Despite the recognized importance of computational thinking, cultivating this skill in students is a challenge. Traditional teaching methods often fail to engage students in meaningful problem-solving experiences that promote the development of computational thinking. Many students struggle to master abstract concepts and apply them to real-world situations, leading to a lack of confidence and interest in STEM fields. To address these challenges, this research proposes the integration of design thinking as a pedagogical approach to enhance students' computational thinking skills.

2. Literature Review

Computational thinking equips individuals with systematic problem-solving skills, enabling them to effectively tackle various challenges. Furthermore, its applications extend beyond computer science to various fields, including science, engineering, the arts, and humanities, fostering interdisciplinary innovation and collaboration (Czerkawski & Lyman, 2015; Pulimood et al., 2016). Additionally, computational thinking enhances critical thinking skills, allowing individuals to assess information, analyze data, and make informed decisions (Wu et al., 2024; Juškevičienė & DagienĖ, 2018). It also promotes creativity by encouraging innovative solutions, driving progress, and new ideas. Lastly, computational thinking enhances learning efficiency by providing students with a structured and logical approach, thereby improving their overall learning experience (McCormick & Hall, 2022).

Design thinking emphasizes empathy, creativity, and iterative problem-solving, providing a framework that encourages students to actively engage with complex problems (Razzouk & Shute, 2012). By fostering a practical, collaborative learning environment, design thinking can help students develop a deeper understanding of computational concepts and improve their ability to think critically and creatively (Lee et al., 2020). Design thinking emphasizes student-centered learning, encouraging active participation and exploration, which stimulates curiosity and creativity (Lee & Hannafin, 2016). Moreover, design thinking focuses on solving complex, real-world problems, aligning closely with key elements of computational thinking such as problem decomposition, pattern recognition, and algorithmic thinking (Henriksen et al., 2017). Additionally, it fosters interdisciplinary learning, allowing students to integrate knowledge from different fields, enhancing their understanding of computational thinking. The iterative process of design thinking encourages learning from failure through continuous feedback and revision, thereby strengthening critical thinking skills. Furthermore, it promotes teamwork and communication, as students collaborate in groups, sharing ideas and perspectives, which is essential for computational thinking.

The purpose of this research is to explore how embedding design thinking into STEM education can enhance students' computational thinking skills and increase their motivation in STEM subjects. By integrating design thinking methodologies, this study aims to create a more engaging and effective learning environment that fosters critical thinking, problem-solving, and creativity. Ultimately, the research seeks to identify best practices for educators to implement design thinking in STEM curricula, thereby preparing students for future challenges in a technology-driven world.

Research Question:

1. To what extent does the integration of design thinking in STEM education effectively promote the development of computational thinking skills in students?
2. Does the integration of design thinking in STEM education have varying degrees of impact on the development of computational thinking skills among students of different genders?

3. Research method

3.1 Participants

The participants of the study are 30 students from a primary school located in Shenzhen City, Guangdong Province, in China. Among them, eight students from grade 4, 12 from grade 5, and ten from grade 6. There are 19 males and 11 females. The students are from a community organized by the school and focus on using different tools and kits to solve questions. The study lasted one month. The pre-test, practice class, and post-test were distributed in the first, third, and fourth weeks. Each class lasts one hour.

3.2 Procedures

Phase One: Contextual Integration and Problem Definition. In the previous lesson, students engaged with the "Flower" curriculum. In this session, students will reflect on their observations, placing particular emphasis on the challenges they encountered. They are encouraged to formulate questions and articulate any concerns they may have regarding the watering process. By focusing on empathy and clearly defining the problem in this phase, students will cultivate a strong value system and motivation for problem-solving. This phase integrates the idea of “empathize” and “define” from the design thinking, promotes critical thinking and collaboration, thereby enriching the overall learning experience.

Phase Two: Exploration of Solutions. This phase aims to address the issues identified in Phase One. Students will engage in brainstorming sessions to propose potential solutions for improving cultivation methods, including aspects such as watering, lighting, and temperature control. They will be introduced to the context through a video showcasing future cultivation techniques utilizing artificial intelligence. Following this, a discussion will be organized regarding the application of technology in managing farms or gardens. After the brainstorming session, the instructor will guide students in evaluating the feasibility of their ideas. In this step, students are required to formulate a plan and outline specific steps to address the identified problems. This process integrates the idea of “ideate” from the design thinking, entails deconstructing the issues, and applying creative thinking to generate innovative ideas.

Phase Three: Prototype Design. Following the idea of “prototype” from the design thinking, in this phase, students will develop a system to monitor the temperature, humidity, and light conditions of the plants they are cultivating. This prototype will serve as a practical application of the concepts generated in Phase Two. Each group will be provided with micro:bit microcontrollers (which they have utilized in the previous lesson), sensors for measuring temperature, humidity, and light, as well as additional materials for constructing the physical setup (such as wires and breadboards). The installation will encompass both programming and physical components. In the physical aspect, students will correctly connect the sensors to the micro:bit microcontroller. Drawing on their previous experiences with setup and installation, they will create a pin distribution diagram to guide their connections. In the programming component, students will write a program that includes initial sensor readings and displays data values on the micro:bit screen or transmits the data back to a computer. During this phase, students are required to apply STEM knowledge to construct the design prototype. Additionally, their practical skills and experience in utilizing technology (micro:bit) are crucial for ensuring the success of the prototype. Furthermore, collaboration will be encouraged, allowing them to share roles and enhance teamwork and learning.

Phase Four: Testing. Following the idea of “test” from design thinking, in this phase, students will evaluate their prototypes in the garden by collecting data on the temperature, humidity, and light conditions of the peanut plants. This stage will enable them to assess the functionality and effectiveness of their designs. Following the initial testing, a group discussion will be held, allowing students to share their observations and experiences.

3.3 Data collection and analysis

The computational thinking of students is from the Bebras Challenges. Bebras Challenges are international competitions aimed at promoting computational thinking among students aged 6 to 19. These challenges involve interactive tasks that foster logical reasoning and problem-solving skills. Participants enhance their computational abilities while engaging in a fun and collaborative environment. Students will take a pre-test before the study and a post-test after the study. There are four challenges, two difficulty A and two difficulty B, in the pre-test. Ten challenges, three difficulty A, three difficulty B, and four difficulty C, were in the post-test. The pre-test lasts 15 minutes and the post-test lasts 45 minutes. This study employs statistical analysis and a t-test to analyze the difference between pre- and post-test and between genders. The study employs Python to analyze the data.

4. Results

4.1 Statistical analysis

Table 1 demonstrates the statistical analysis results of students' pre- and post-tests. Based on the analysis of the Pre-test and Post-test data, significant differences in participants' performance across various difficulty levels (A1-C4) are evident. The A group generally has higher means, indicating that participants have a good grasp of the lower-difficulty questions, with A1 having a mean of 4.13 and A2 4.4. In contrast, the B group shows more variability, with B1's mean significantly increasing from 0.2 to 6.2, and B2 rising from 5 to 8.6, demonstrating notable learning outcomes in medium-difficulty questions. However, the C group's means are relatively low, particularly for C2 (2.53), reflecting the challenges faced by participants with higher-difficulty questions. Additionally, B3 had one unanswered question in the post-test, which may have affected its mean (-1.5). Overall, most groups showed improvement in the post-test, especially the B group, indicating significant learning outcomes in medium-difficulty questions. Table 2 shows the results of the paired samples test. The results indicated a significant difference between the pre- and post-test.

Table 1. The statistical analysis results of students' computational thinking in pre- and post-tests

	Min	Nmin	Max	Nmax	0	N0	Mean
Pre-test							
A1	-2	7	6	23	-	-	4.13
A2	-2	6	6	24	-	-	4.4
B1	-3	22	9	8	-	-	0.2
B2	-3	10	9	20	-	-	5
Post-test							
A1	-2	0	6	23	0	7	4.6
A2	-2	7	6	23	-	-	4.13
A3	-2	5	6	25	-	-	4.6
B1	-3	7	9	23	-	-	6.2
B2	-3	1	9	29	-	-	8.6
B3	-3	24	9	9	0	4	-1.5
C1	-4	13	12	17	-	-	5.06
C2	-4	17	12	13	0	1	2.53
C3	-4	14	12	16	-	-	4.53
C4	-4	11	12	18	0	1	5.73

Table 2. Paired Samples Test

Paired Differences							Significance	
			95% Confidence Interval of the Difference					
Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
-30.833	26.672	4.870	-40.793	-20.874	-6.332	29	0.000	0.000

4.2 Computational Thinking difference in Males and Females

The study conducted a t-test to answer research question two. The results of the independent samples t-test indicate that there is no significant difference in scores between males and females. Specifically, in the pre-test, the t statistic is 0.853 and the p-value is 0.4020, both exceeding the significance level of 0.05. This suggests that gender does not have a significant effect on scores. In the post-test, the mean score for the male group is 46.1, with a standard deviation of 26.27; the mean score for the female group is 46.18, with a standard deviation of 28.82. The t-statistic is -0.008, and the p-value is 0.994. This indicates that there is no significant difference in scores between males and females ($p > 0.05$). Therefore, we fail to reject the null hypothesis, suggesting that gender does not have a significant effect on scores.

5. Conclusion

This study explores the impact of integrating design thinking in STEM education on the development of students' computational thinking skills, as well as analyzing the performance differences among students of different genders. Through statistical analysis of pre-test and post-test data, we found significant differences in participants' performance across various difficulty levels (A1-C4). The A group generally had higher means, indicating that participants had a good grasp of lower-difficulty questions. In contrast, the B group showed significant improvement in medium-difficulty questions, particularly with B1 and B2, demonstrating a positive effect of integrating design thinking on learning outcomes. However, the C group had relatively low means for higher-difficulty questions, reflecting the challenges faced by participants in this area. Regarding the second research question, the results indicated that gender does not significantly affect student scores. In both the pre-test and post-test, the mean scores for males and females were nearly identical, and the statistical analysis (t-test) results did not reach significance ($p > 0.05$). This suggests that gender is not an important factor in the development of computational thinking skills. Overall, the integration of design thinking shows a positive effect on promoting students' computational thinking skills, especially in medium-difficulty tasks. However, gender has a limited impact on learning outcomes, indicating that educational interventions should focus more on the effectiveness of teaching methods rather than gender differences. This provides valuable insights for future applications of design thinking in STEM education and offers a reference for educators in designing curricula.

6. Limitations and suggestions

The study still has some suggestions and limitations. Firstly, the study employed a small group as participants. And the study only examined the gender difference in computational thinking. In future research, more participants can be included in the study to conduct a more detailed analysis or to find out the possible factors that may influence computational thinking. Moreover, the process of how design thinking promotes students' computational thinking is also worth exploring. Therefore, future research can be carried out from the perspective of learning science to explore the internal mechanism of the development of computational thinking.

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人工智能反馈对大学生学术英语写作表现的影响：元分析

Effects of AI Feedback on Students' Academic Writing Performance in Higher Education: A Meta-analysis

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【摘要】人工智能 （AI）反馈在英语写作教学中的应用越来越广泛，但是学界对人工智能反馈能否有效促进英语写作教学却一直存在争议。本研究对 38 篇 AI 反馈实证研究进行了三水平元分析，探究其在大学生学术英语写作表现中的效果及影响因素。结果显示，AI 反馈具有中等效应，AI 反馈工具、反馈内容、反馈模式、人机混合反馈中的序列均对 AI 反馈的学习效应有显著影响。本研究结果对大语言模型时代下英语写作教学具有一定的启示，特别是在如何优化 AI 反馈工具的设计和使用方面。
【关键词】人工智能反馈；大学生学术英语写作表现；三水平元分析；人机混合反馈

Abstract: *Feedback provided by artificial intelligence is increasingly common in English academic writing, yet controversies exist regarding its effectiveness. This study conducted a three-level meta-analysis of 38 valid studies to explore AI feedback's impact on students' academic English writing performance and its influencing factors in the higher education setting. Results indicated a moderate effect size, with significant influences from AI feedback tools, content, mode, and the sequence of human-AI hybrid feedback mode. These findings offer valuable insights for English writing instruction in the AI era, particularly in optimizing the design, implementation, and integration of AI feedback tools into pedagogical practices.*
Keywords: AI feedback, student academic writing performance, three-level meta-analysis, human-AI hybrid feedback mode

1. 引言

生成式人工智能（GenAI，如 *ChatGPT*、*Deepseek* 和 *Copilot*）的兴起进一步推动了 AI 写作反馈的发展。GenAI 基于大型语言模型（LLM），能够生成接近人类水平的文本，为学习者提供实时反馈，帮助其在写作方面取得进步。然而，AI 反馈的效果仍存在争议。自动写作评估(AWE)工具在话语层面（如内容和组织）表现较弱，且缺乏与学习者的互动(Chen & Cui, 2022)；聊天机器人和机器翻译则因对上下文理解不足(Guo et al., 2024)。GenAI 虽然有一定的效果，但也面临着知识转移不足、道德问题以及抑制思辨能力发展的挑战(Fan et al., 2024)。

鉴于现有研究结果的多样性，有必要通过元分析系统量化 AI 反馈对学生英语学术写作表现的影响，以更全面地评估其效果和局限性，为未来的反馈实践提供科学依据。因此，本文提出以下研究问题：1）人工智能反馈对大学生学术英语写作表现的总体效应如何？2）哪些因素会影响人工智能反馈对大学生学术英语写作表现的效应？

本文中 AI 反馈的操作定义基于于 Carless 和 Boud (2018)提出的定义进行了改编。AI 反馈的操作定义为：学习者主动寻求、接收并理解由 AI 生成的关于其学习表现的信息，并利用这些信息优化其学习策略的过程。而学术英语写作的操作定义指的是在大学阶段用于评估学生英语能力的写作形式(Zhai & Ma, 2023)。

2. 研究方法

2.1. 文献检索

文献检索于 2024 年 12 月进行。选取的数据库有：Web of Science，Scopus 和 EBSCO。为确保全面地检索相关文献，并未对时间范围和文献类型进行限制。论文筛选的关键词与“AI 反馈”“写作表现”“高等教育”有关。我们还采用了人工检索，范围包括综述类文章及教育技术类期刊。通过以上检索策略，去重后最终检索到英文论文 601 篇。

2.2. 文献筛选

文献筛选标准如下：1）必须是在高等教育语境下使用了 AI 反馈的实证研究 2）必须是组间或组内比较的实验研究设计 3）必须包含计算效应量所需的统计信息 4）必须通过文献质量评估。文献质量评估采用了改编版的 Effective Public Health Practice Project (EPHPP) 工具(Thomas 等，2004；Yan 等，2022)，涵盖了五个维度：参与者选择偏倚、研究设计、混杂因素、数据收集方法以及参与者退出情况。每个维度均按照“强”“中”“弱”三个等级进行评分。若有一个“弱”评级则被评为质量好的研究，两个“弱”为质量中等，超过两个“弱”则为质量较差的研究 (Yan 等，2022)。质量评估由两位在读教育学博士生进行，对于存在分歧的部分，两位评估者通过讨论达成一致。评定为质量较差的研究则被排除。经筛选，纳入文献总计 39 篇。

2.3. 文献编码

本研究对纳入的文献按照以下方面进行编码：1）所使用的 AI 反馈工具 2）是否有对受试进行反馈工具使用的培训 3）反馈类型 4）反馈内容 5）反馈来源 6）人机混合反馈中的序列。编码过程由两位教育学博士生进行，一致性检验为 Cohen’s alpha = .88，对于存在歧义的地方，两位编码人员进行讨论以达到一致意见。

2.4. 数据分析

我们采用 Cohen’s d (Cohen, 1988)来计算效应量指标,并将 Cohen’s d 转换为 Hedges’ g (Hedges, 1981)，因为其能够在小样本研究中提供无偏差的效应量估计(Lipsey & Wilson, 2001)。写作表现的测量通常包括多个变量。因此，一个研究通常会报告多个效应量，而这些效应量之间可能存在依赖性(Cheung, 2014)。本研究采用了三水平元分析因其能够避免分析中的潜在偏差(Ngo et al., 2024)。

除了探究 AI 反馈对学生英语学术写作成绩影响的总体效应外，还对调节变量进行分析。为保证研究结果的稳健性，我们进行了异常值检测。在纳入的文章中，有一篇文章的效应量为 $g = 52.32$ (Rad et al., 2023)，超出了($\bar{x} - 3SD$，$\bar{x} + 3SD$)的范围(Acuna & Rodriguez, 2004)，因此将其移除。最终纳入本元分析中的研究有 38 篇。

3. 研究结果

3.1. 总体效应量

表 1 中呈现了 AI 反馈对大学生学术英语写作的总体效应量。根据三水平元分析的结果，总体效应量为 $g = 0.78$，达到中等效应(Plonsky & Oswald, 2014)。

表 1 效应量及异质性检验结果

	加权效应量			95% 置信区间		异质性						
	k	g	SE	$Lower$	$Upper$	Q	df	p	τ^2_{level3}	I^2_{level3}	τ^2_{level2}	I^2_{level2}
三水平	221	0.78	0.21	0.36	1.19	3,915.71	220	< .0001	0.67	66.51%	1.46	30.4%

3.2. 调节变量检验

本研究进行了调节变量检验，调节变量的分析结果如表 2 所示。值得注意的是，在 AI 反馈工具、反馈内容、反馈模式及混合反馈中的序列四个调节变量中发现了显著的调节作用。

在AI反馈工具中，GenAI的效应量最大($g = 1.85, p < 0.001$)，其次是AWE ($g= 0.44, p < 0.01$)，聊天机器人 ($g = 0.04, p > 0.05$), 及机器翻译 ($g = -0.04, p > 0.05$)。GenAI 的表现优于其他三种工具。在不同的反馈内容下，整体反馈($g = 1.95, p < 0.001$)的效应量大于局部反馈($g = 0.56, p < 0.01$)及两者并存的反馈 ($g = 0.82, p < 0.05$)。

在反馈模式中，人机混合反馈的效应量($g = 1.04, p < 0.05$)高于仅使用 AI 工具进行反馈($g = 0.24, p > 0.05$)。由于人机混合反馈的效应量比仅 AI 反馈的效应量更大，我们对人机反馈中的序列进行了进一步的比较。如表 2 所示，序列 AI-人工-AI ($g = 2.72$)的效应量最大，其次是人工-AI-人工($g = 0.91$)，紧接着是 AI-人工($g = 0.76$)，效应量最小为人工-AI ($g = 0.26$)。

该分析还考察了其他调节变量，但未发现有显著的调节作用。提供使用 AI 工具的培训($g = 0.83$，$p < 0.01$)比未提供培训($g = 0.65$，$p < 0.05$)产生了更大的效应量。此外，仅提供评语($g = 1.18$，$p < 0.01$)比混合反馈模式（即评分加评语，$g = 0.51$，$p < 0.05$）的效应量更大。

表 2 调节效应分析

调节变量		效应数量	效应量 [95%置信区间]	t 值	p 值
AI 反馈工具	GenAI	55	1.85 [1.11, 2.59]	$t_{(3, 217)} = 3.76$	0.01*
	AWE	162	0.44 [-0.002, 0.88]		
	聊天机器人	1	0.04 [-2.6, 2.68]		
	机器翻译 MT	3	-0.04 [-2.34, 2.26]		
给学生提供 AI 工具培训	有提供	164	0.83 [0.33, 1.32]	$t_{(1, 219)} = 0.14$	0.71
	无提供	57	0.65 [-0.15, 1.45]		
反馈类型	评语	91	1.18 [0.57, 1.79]	$t_{(2, 219)} = 2.97$	0.09
	评语+评分	130	0.51 [0.002, 1.01]		
反馈内容	整体反馈	16	1.95 [0.99, 2.91]	$t_{(2, 218)} = 3.83$	0.02*
	局部反馈	143	0.56 [0.09, 1.04]		
	混合	62	0.82 [0.24, 1.41]		
反馈模式	仅 AI 反馈	86	0.24 [-0.13, 0.88]	$t_{(1, 219)} = 6.72$	0.01*
	人机混合反馈	135	1.04 [0.57, 1.45]		
人机混合反馈中的序列	AI-人工	82	0.76 [0.37, 1.14]	$t_{(3, 131)} = 4.14$	0.008**
	人工-AI	17	0.26 [-0.22, 0.74]		
	AI-人工-AI	21	2.72 [0.45. 4.31]		
	人工-AI-人工	15	0.91 [-0.09, 1.74]		

4. 讨论与总结

本研究对 38 项 AI 反馈实证研究进行了元分析。结果显示，AI 反馈的效应值为 0.78，说明 AI 反馈能提高大学生英语写作表现。通过调节变量检验，我们发现四个对总效应量有显著贡献的调节变量，分别是 AI 反馈工具、反馈内容、反馈模式及人机混合反馈中的序列。

该元分析为融合智能(hybrid intelligence)这一概念提供了支撑。融合智能由 Akata 等(2020)提出，通过人类与机器智能的互补优势，以实现那些仅靠人类或机器单独无法完成的任务。本研究中，人机混合反馈对总体效应影响更大，可以归因于人机混合反馈可以达到人工与 AI 之间的意义协商，进而达到融合智能。通过观察人机混合反馈模式下序列之间的差异，我们也可以发现 AI-人工-AI 及人工-AI-人工的这两组迭代序列会比线性序列更加有效。根据 Nguyen 等(2024)的讨论，线性序列倾向于将 AI 仅仅用作信息的补充，缺乏 AI 与学生之间深度互动，从而影响写作效果。

本研究进一步表明 AI-人工-AI 这一序列比人工-AI-人工所产生的作用更大，自我决定理论(Ryan & Deci, 2020)可用于解释这一现象。AI 作为提供即时反馈，帮助学生了解自己写作中表现较好和需要改进的方面，学生可自行决定是否采纳 AI 所提供的反馈，满足其胜任需求和自主需求。随后，人工反馈能够提供情感支持和进一步的指导，满足其关系需求。最后，学生通过 AI 的评估明确看到自己的成长，进一步强化胜任感。若先有人工反馈，学生可能因早期收到主观评价而产生防御心理，从而抑制自主需求及胜任需求。

本研究还发现，整体反馈和混合反馈的有效性较高，而局部反馈效果中等，然而 Ngo 等(2024)发现整体和局部反馈效果显著，而混合反馈效果较弱。差异可能源于 AI 反馈工具的不同。Ngo 等主要使用 AWE 工具，而本研究还采用了生成式 AI、聊天机器人和机器翻译，这些工具在提供局部和整体反馈方面表现更全面。混合反馈可能因同时要求语法纠正和结构建议而导致学生产生认知负荷，而整体反馈更受学生重视，因为其能直接影响文章整体质量。

AI 反馈工具的不同也对总体效应量产生了显著影响，其中 GenAI 的效应量较其他工具更大。GenAI 基于大量语言数据训练，能够通过对话生成反馈，支持迭代改进。相比之下，AWE、聊天机器人和机器翻译依赖预定义规则，缺乏对自然语言的深度理解。

对 AI 工具的使用进行培训和反馈类型这两个变量的调节作用并不显著。然而，有培训的效应量大于无培训。在 GenAI 时代，培养学生如何使用 AI 工具显得尤为重要。此外，反馈类型的效果也显示出差异：仅提供评语的反馈比"评分+评语"反馈更有效。评语能够帮助学生深入理解作品并促进有意义的反思。

综上所述，本研究为 AI 反馈在写作教学中的应用提供了实证支持，并强调了人机协作、迭代反馈序列以及生成式 AI 的重要性。未来研究可进一步探索如何通过系统化培训帮助学生更有效地使用 AI 工具，以及如何优化反馈设计（如结合情感支持和个性化指导）来最大化 AI 反馈的教育价值。此外，在 GenAI 时代，教师的角色将更多体现在与 AI 的协作中。如何适应这一角色转变，通过运用 AI 技术提升自身及学生的反馈素养，也值得进一步探索。

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高等教育中科技增强型对话式反馈——一项批判性文献综述

Technology-enhanced Dialogic Feedback in Higher Education: A Critical Review

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【摘要】 科技增强型对话式反馈正在逐渐取代传统的单向反馈方式，成为高等教育反馈研究与实践的重要趋势。该批判性文献综述探讨了科技增强型对话式反馈的设计元素、反馈效果及影响因素。研究发现，反馈设计中缺乏社会情感准备、形式化内省以及前馈探讨；反馈效果缺乏实证干预实验的数据支持；影响反馈活动实施与效果的研究未充分考虑社会文化维度，各因素之间的相互作用亦不明确。该综述为科技增强型对话式反馈机制的研究提供了重要参考，并提出优化建议，以提升反馈效益，促进学生学习。
【关键词】 对话式反馈；科技；设计元素；效果；影响因素

Abstract: *Technology-enhanced dialogic feedback is gradually replacing traditional one-way feedback and has become an important trend in feedback research and practice in higher education. This critical literature review explored the design elements, effects and influencing factors of technology-enhanced dialogic feedback. The findings indicate that the feedback design lacks social-affective preparation, formalized reflection and feed-forward discussion; The effects of feedback lack empirical data support from intervention studies; Research on the factors influencing the implementation and effectiveness of feedback activities has not adequately considered sociocultural dimension, and the interplay among various factors remains unclear. This review provides important references for the study of technology-enhanced dialogic feedback mechanisms and offers optimization suggestions to enhance feedback effectiveness and improve student learning.*
Key words: dialogic feedback, technology, design elements, effects, influencing factors

1. 前言

对话式反馈是指师生或同伴之间围绕学习反馈“分享理解、协商意义、澄清期望的互动交流过程”（Carless, 2012, p. 90）。对话式反馈有助于提升学生的反馈参与度，促进深度学习和自我调节能力的发展，尤其契合高等教育对自主学习能力的培养需求（Beaumont, 2011)。然而，在高等教育大众化的背景下，师生互动空间正被逐渐压缩（Nicol, 2010)，对话式反馈的实施面临挑战。在此情境下，科技平台通过突破时空限制、支持异步互动和规模化个性化对话，为重建高质量的反馈交流提供了新的可能性。

由于其互动性和动态性，科技增强型对话式反馈的实施颇具挑战性。 Pitt 和 Winston（2020）指出，尽管科技增强的反馈表面上似乎包含对话元素，但实际上往往只是单向传递的信息重复，并未有效促进学生的参与和理解。为了避免“浅表”的对话反馈，有必要对对话反馈机制进行深入理解。本研究对相关文献进行了批判性综述，旨在总结科技增强型对话式反馈的设计元素、反馈效果及其影响因素，为优化科技增强型对话式反馈提供新的思路。

2. 科技增强型对话式反馈定义及机制

科技增强型对话式反馈是指利用科技平台来促进互动性反馈的过程。在这一过程中，学生处于主导地位，积极与教师及同伴围绕反馈内容进行深入对话，以深化理解、共筑知识。

Beaumont 等人（2011）指出，对话式反馈通过持续的对话提供学习支架，而不仅仅是单一的“告知”和“回应”。他们提出了对话式反馈循环，将反馈视为一个结构化的指导过程，分为

三个阶段：预备指导、任务指导和成果反馈。

科技增强型对话式反馈循环符合社会建构主义学习理论（Carless & Boud, 2018）。根据该理论，知识和意义是通过社会互动构建的。教师与同伴的对话支持能够有效引导个体认知达到最近发展区（ZPD），促使反馈作用最大化，促进深度学习和认知发展（Nicol, 2010）。

尽管科技增强型对话式反馈具有促进学习的巨大潜力。其实施过程不可避免地受到社会物质因素的影响（Wood, 2024），从而呈现不同程度的反馈参与、反馈吸收及学习效果。本综述旨在明确科技增强型对话式反馈的设计元素，反馈效果，并分析其影响因素，以加强对对话式反馈机制的整体理解。其研究问题如下：

1）现有研究中关于科技增强型对话式反馈的设计突出了哪些元素？

2）科技增强型对话式反馈对学生学习产生了怎样的作用？

3）哪些因素会影响科技增强型对话式反馈的实施与效果？

3. 研究方法

3.1. 文献检索与评估

本研究确定检索关键词为“dialogic feedback” 和 “higher education”。研究年限限定为 2010-2024。在 Scopus、Web of Science 和 ERIC 数据库中共检索到 624 篇文献。去除重复项后，剩余 432 篇。通过查阅题目和摘要评估主题相关性，筛选出 192 篇文献。再根据表 1 中的纳入和排除标准审查全文，最终纳入 16 篇文献。

表 1 文献筛选标准

标准	纳入标准	排除标准
1）是否密切关联对话式反馈主题	是	否
2）是否属于概念性论文或综述研究	否	是
3）在对话式反馈过程中是否采用科技平台	是	否
4）是否在高等教育环境中开展	是	否
5）是否涉及反馈设计、效果或影响因素	是	否

3.2. 数据提取与整合

为达成研究目的，本研究制定了文献信息编码方案，从以下三个方面进行数据提取：1）设计元素，包括预备指导、任务指导和成果反馈各阶段；2）反馈效果，包括学生反馈素养和学业成果；3）影响因素，包括个人、物质和情境因素。

4. 研究结论与讨论

4.1. 科技增强型对话式反馈设计元素

本研究梳理了对话式反馈循环各阶段的设计元素（如表 2 所示）。其中，预备指导阶段强调帮助学生进行反馈的认知和情感准备，这与 Yang & Carless (2013)有效反馈三角模型不谋而合。他们强调，反馈涉及认知、社会情感和结构方面。然而，该研究发现较少研究设计包含对学生社会情感的先导指引。未来研究及实践应重视对话式反馈的社会情感氛围。信任及和谐关系是促进反馈对话顺利进行的保障（Carless, 2012）。

任务指导阶段则以多轮修改为契机，通过外源对话和内省对话的交互作用，支持师生协商意义，共筑知识。值得强调的是，外部反馈必须引发学生的内省对话，否则学生难以从反馈中建构意义并指导未来学习（Nicol, 2010）。该研究发现大部分对话式反馈的实施虽重视内省过程，

却并未将其呈现在反馈活动设计中。本研究建议将内省对话形式化，以促进对话构建过程。

成果反馈阶段不仅是对任务表现的评估与总结，更是通过反思与前馈而推进反馈活动“螺旋式上升”，从而形成闭环的重要环节。Carless（2019）指出，有效的反馈设计不仅应当帮助学生在当前任务中发现问题并加以改进，还应提升学生应对未来任务的策略。然而，该研究发现，前馈设计鲜少，未来研究应加强重视。

表 2 科技增强型对话式反馈设计元素

反馈阶段	设计元素	实施细节
预备指导阶段	反馈培训	培训内容：反馈重要性；任务目标；反馈流程与策略 培训方式：教师进行概念灌输；学生参与讨论探索
	标准示例	提供、探讨、应用
	情感准备	建立关系；情感调节
任务指导阶段	修改机会	多轮修改
	外源对话	互动对象：教师、同伴、教师与同伴 互动模式：同步；非同步；书面；口头；多模态
	内省对话	互动对象：自我 互动模式：书面；口头；网络保存与分享
成果反馈阶段	总结反思	反思学习，总结经验
	前馈探讨	答疑解惑；指导行动；探讨策略

4.2. 科技增强型对话式反馈效果

科技增强型对话式反馈能够有效提升学生反馈素养。在社会情感方面，学生对反馈的看法转变为将其视为有益和建设性的对话（Wood，2022），表现出更高的欣赏度、自信心和情感调节能力（Hui et al.，2024）。在认知能力方面，反馈对话提升了学生的判断和评价能力（To , 2022），促使他们通过反思和主动寻求反馈来积极参与和改进任务。

科技增强型对话式反馈能够有助于提升学生学业成果。研究表明，科技增强型反馈对话显著提升了学生的写作成绩，对写作的组织、内容和语言运用产生了积极影响（Saeed and Alharbi，2022）。科技增强型反馈对话还改善了深度学习、批判性思维和知识整合能力，培养了元认知技能，并增强了自我反思意识（Alqefari, 2022）。此外，科技增强型反馈对话促进了支持性学习社区的形成，增强了学生与教师和同伴之间的情感和信任（Wood, 2021），提升了他们的学习自信心。

然而，关于科技增强型对话式反馈效果的证据主要依赖于学生的自我报告。未来研究应更多采用干预研究方法，以提供更具说服力的实证支撑。

4.3. 科技增强型对话式反馈实施的影响因素

该研究发现，个人因素、物质因素和情境因素均对科技增强型对话式反馈的实施和效果产生影响。个人因素方面，学习者动机至关重要，高度激励的学习者更积极，而动机不足者则表现消极。此外，语言能力和自信心也影响参与度，较高的语言能力有助于提升科技增强型对话式反馈效果。物质因素方面，科技平台作为支持性学习空间能够提高自我调节和参与度，但科技的可用性和便利性也可能受到技术问题的制约，平台互动的时空因素同样影响学生参与。情境因素方面，社会文化信念和人际关系影响反馈的认知与体验。有研究指出参与者在其文化中将反馈视为批评，因此对给予和接受反馈感到不适。人际关系对对话式反馈的展开至关重要（Yang & Carless，2013)。支持性的社会关系增强了参与者的心理安全感和信任，提升了参与意愿，但有时也可能限制反馈质量。该发现契合社会物质理论（Gravett, 2020）。在反馈活动中，

个体与社会、情境和物质层面的“参与者”相互关联（Gravett, 2020, p.270），形成了一个“相互依存的整体”，从而塑造了反馈实践和学习互动（Ajjawi et al., 2017, p131）。

该研究注意到，关于社会文化对反馈对话过程影响的研究为数不多。另外，各影响因素之间的交互作用也尚不明确。反馈互动是“无界”和“关联性”的（Gravett & David Carless, 2024, p.144）。未来研究应超越即时社会环境，探讨更广泛的时空背景以及各因素之间的交互作用，强化对多种因素共同影响反馈互动和学生学习的实证研究。

4.4. 科技增强型对话式反馈设计架构

综合上述研究发现，如图 1 所示，科技增强型反馈对话的设计应充分考虑到个人、情境及物质因素，合理利用科技平台，展开持续循环的准备指导、任务指导及成果反馈，以发展学生反馈素养，进而提升其学业能力。

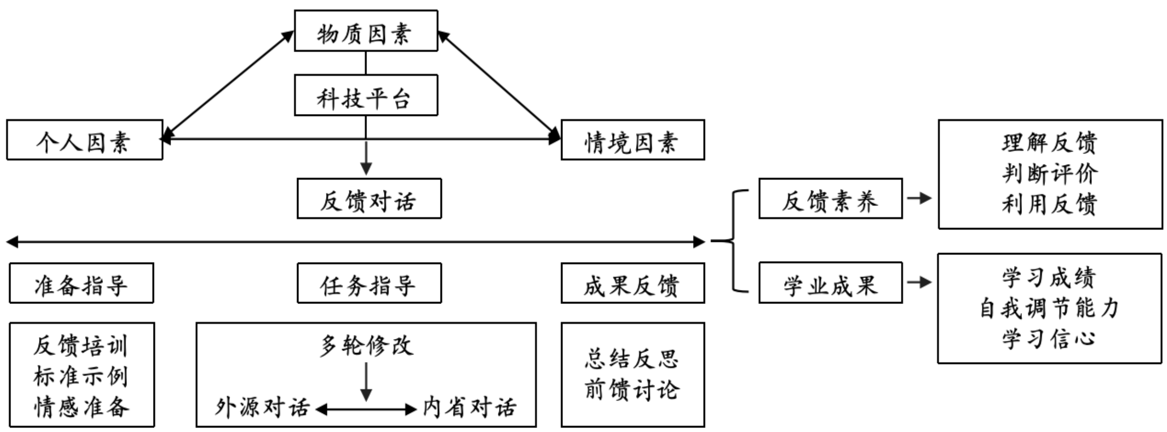

图 1 科技增强型反馈对话设计架构

5. 结语

本文通过文献综述，对现有科技型对话式反馈活动的设计元素、活动效果及影响因素进行梳理和总结，提出现阶段相关研究空白，对未来该领域研究提出了启示与建议。

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AI 技术在 STEM 教育中的应用：教师的观点

Application of AI in STEM Education: Teachers' perceptions

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【摘要】 本研究探讨教师对人工智能（AI）融入 STEM 教育的体验和看法，旨在为未来的教育改革提供参考。研究计划基于对 30 名在职 STEM 教师的访谈，聚焦于 AI 在教育中的应用及其对学生学习成果的影响。通过对目前已经收集的一份数据进行扎根理论分析，结果表明教师对 AI 的看法总体积极，认为 AI 能有效提升学生的认知、情感和行为学习成果。具体而言，AI 工具在项目式学习、游戏化教学等策略中得到了应用，支持学生的个性化学习与协作。然而，教师也面临挑战，如教育资源的平等分配、教师与学生的 AI 素养不足等。研究强调，社会和学校需提供支持以确保教育平等，教师和学生应提升 AI 素养，而技术人员则需持续改进 AI 技术，以实现更智能和个性化的教育体验。
【关键词】 STEM 教育中的人工智能; 教师的观点; 扎根理论

Abstract: *This study explores teachers' experiences and perceptions of integrating Artificial Intelligence (AI) into STEM education to inform future educational reform. The research program is based on interviews with 30 in-service STEM teachers, focusing on the use of AI in education and its impact on student learning outcomes. Through grounded theory analysis of the one piece of data that has been collected so far, the results indicate that teachers have an overall positive view of AI as effective in enhancing students' cognitive, affective, and behavioral learning outcomes. Specifically, AI tools are used in strategies such as project-based learning and gamified instruction to support personalized student learning and collaboration. However, teachers also face challenges, such as equal distribution of educational resources and insufficient AI literacy among teachers and students. The study highlights that society and schools need to provide support to ensure equality in education, teachers and students should improve their AI literacy, and technicians need to continually improve AI technologies to enable smarter and personalized educational experiences.*
Keywords: AI in STEM education, grounded theory, teachers' perceptions

1. 前言

近来，人工智能越来越多地融入我们的日常生活，包括经济、科学、工程、教育等各个方面。在教育领域，人工智能也在逐步改变教师的教学方式、学生的学习体验和评价方式，如智能辅导、个性化学习、实时反馈等。特别是随着大型语言模型（LLM）的出现，如 ChatGPT，人工智能已开始应用于语言教育（Hınız, 2024）、医学教育（Zidoun & Mardi, 2024）、数学教育（Canonigo, 2024）、科学教育（Ng et al., 2024）等领域。

在 STEM 教育中，有大量的实践活动需要学生去探索。在这个过程中，人工智能的应用，如聊天机器人、智能辅导系统、识别系统等，可以帮助学生在探究过程中，增强对知识的理解和高阶思维能力（Lin et al., 2024）。例如，Sakulkueakulsuk 等人（Sakulkueakulsuk et al., 2018）利用游戏化教学策略，将机器学习融入课程，设计并实施了中学 STEM 跨学科活动。Li 等人（Li et al., 2024）比较了 GPT 辅助教学与传统教学策略对职前 STEM 教师学习的影响，结果表明，实验组学生的批判性思维比对照组更强，认知负荷更低。然而，人工智能在 STEM 教育中的有效应用关键在于教师如何使用。作为教学实践的实施者和引领者，教师的经验对人工智能的进一步优化和教育改革都至关重要。如果未来的教师能够认识和理解人工智能给学生和自己

带来的优势和挑战，扬长避短，就能将人工智能作为教学的助手，为学生带来更优质的学习体验。

因此，本研究旨在探讨教师对人工智能融入 STEM 课程的体验和看法，为未来人工智能融入 STEM 教育提供参考。

2. 研究目的

基于上述背景，本研究的问题可分为 2 个。

1) 将人工智能融入 STEM 教育时，哪些学习成果得到了改善？

2) 如何将人工智能融入 STEM 教育？在实施人工智能融入 STEM 教育时，应考虑哪些关键因素？

3. 研究方法

3.1. 背景和参与者

本研究计划的访谈对象是 30 名中国内地和香港的 STEM 在职和职前教师。采用目的取样法，目前我们已经邀请到了一位具有 3 年以上 STEM 教学经验并有人工智能辅助教学经验的男教师作为被试。该受试者今年 28 岁，拥有教育学硕士学位。访谈前，被试了解了本研究的目的和宗旨，以及他在访谈中的权利，并自愿签署了同意书。

3.2. 访谈问题的设计与开发

访谈问题包括开场问题、核心问题、进一步问题和结束问题。在开场问题中，研究者说明本次访谈的目的和内容，以及参与者的权利。研究人员询问了参与者的基本信息和背景。此外，研究人员还请参与者做自我介绍，并介绍自己在 STEM 教学方面的经验。

随后，根据本研究的研究问题设计了核心问题和进一步的问题。第一个研究问题是，在开展人工智能整合 STEM 教育时，可以提高哪些学习成果。因此，第一个核心访谈问题是：在使用人工智能工具帮助教学后，您认为学生在认知、技能或态度方面有无提高。之后，第二个访谈问题是：您能否分享一些人工智能工具影响学生学习的具体案例？

第二个研究问题旨在获得课程中可以使用的适当教学策略。因此，访谈问题可以分为两个。第一个问题是，您在应用人工智能工具的过程中使用了哪些具体的教学策略？第二个访谈问题是，哪种教学策略特别适合人工智能整合 STEM 课程，为什么？此外，第二个研究问题还希望了解在 STEM 教育中应用人工智能工具时可能面临的挑战或担忧。因此，第三个访谈问题是：您在教学实践中是否遇到过挑战或问题，您是如何解决的？

最后的结束问题是：您对未来在 STEM 教育中使用人工智能有什么看法？以及您是否还有其他想法或经验想与大家分享。

3.3. 数据收集

访谈使用 ZOOM 或者腾讯会议进行。我们使用屏幕录制功能录制对话。然后，逐字转录，将口语对话转换为书面文本。在转录过程中，由于字数限制，我们保留了重要和相关的内容，删除了其他字词。

3.4. 数据分析

数据转录后，采用扎根理论进行数据分析。扎根理论是一种基于建构主义的定性数据分析方法。它侧重于从收集到的数据中提取概念和理论。具体来说，本研究的数据分析可分为四个步骤：开放编码、聚焦编码、轴向编码和理论编码。

4. 初步结果

4.1. 开放编码结果

在初步编码时，采用开放式编码方法，逐行阅读访谈记录并贴上标签。根据每个访谈问题的形式，提取相关有效句子并进行编码，目前的工作对一位教师的访谈记录进行了编码，形成了 60 个开放式编码结果。

4.2. 聚焦编码结果

在开放式编码结果的基础上，本研究进一步对教师对 STEM 教育中 AI 的看法进行了聚焦编码。在编码过程中，删除了与主题无关的内容和句子，提取了与主题相关的词语并进行了分类，数据被分为 26 个子主题。

4.3. 轴向编码结果

根据重点编码中的子主题编码，本研究将其进一步编码为 10 个主题。其中知识发展、高阶思维能力、认知负荷主要涉及学生认知学习结果的发展，因此根据布鲁姆学习目标分类法，将其归入认知学习结果。动机和兴趣主要涉及学生情感学习结果的发展，因此被归入情感学习结果。参与是行为学习成绩的发展，所以归入行为学习结果。学习助手和个性化学习主要涉及 AI 对学生学习的支持，因此被归类为 AI 角色。基于项目的学习、游戏化和基于游戏的学习与教师在教学过程中使用的教学策略高度相关，因此本研究将其归类为教学策略。引导探究、讲解、互动、生成产品主要涉及 AI 的使用阶段，因此将其归类为 AI 整合策略。 对于学校支持、经济支持和教育平等，他们与所需的支持高度相关，因此被归类为资源问题。教师的人工智能素养、技术接受度、对 AI 的批判性思维主要涉及教师准备要求，因此被归类为教师发展。而学生的人工智能素养、学生的批判性思维能力、认知负荷则可归类为学生问题。至于 AI 的准确性、技术改进、AI 的知识性，则可归类为 AI 的改进。

4.4. 理论编码结果

此外，10 个主题被编码为 3 个一般主题。认知、情感和行为学习成果被编码为有效性，因为它主要讨论的是AI在学生学习成绩中的有效性。认知、情感和行为学习成果可归类为使用AI的有效性。AI 角色、教学策略和 AI 整合策略与 AI 辅助课程中使用的教学法高度相关，因此将其归为教学法。对于资源问题、教师发展问题、学生问题、AI 改进问题，我们将其归类为挑战。

Table 4 Theory coding

一般主题	主题
AI 的有效性	认知 情感 行为
教学法	AI 角色 教学策略 AI 融合方法
挑战	资源 教师发展 学生问题 AI 改进

5. 初步结论

通过对三个主题、10 个专题和 26 个子主题的编码，我们可以得出结论：总体而言，教师对 AI 融入 STEM 教育的看法是积极的，但也存在一些问题和挑战。具体而言，它能有效改善学生的认知、情感和行为学习成果。此外，它还可用于项目式学习、游戏式学习和游戏化教学策略，支持学生的个性化学习、协作，并作为学习工具。然而，它也面临着一些挑战，对社会和学校来说，需要确保教育平等，财政支持和学校支持也很重要。对于教师和学生来说。他们需要培养自己的人工智能素养，以确定如何更好地使用 AI 来支持学习过程。同时，技术人员也应改进 AI 本身，使其更加智能化和个性化。

6. 下一步研究计划

迄今为止，我们邀请了在职 STEM 教师参与访谈，虽然这位教师的观点为我们的研究提供了宝贵的第一手资料，但我们认识到，仅依赖于单一的案例很难全面代表 STEM 教师群体的普遍看法。因此，初步的研究结果应作为参考，而非最终结论。下一步中，我们计划继续扩大参与者的范围，邀请更多在职及曾任教的 STEM 教师参与访谈。这将帮助我们更深入地了解各类教师在课堂中采用 AI 技术的看法与经验。

为了保证我们的研究过程的系统化和科学性，我们将借助扎根理论进行进一步的编码分析。这种方法使得我们能够提炼出教师们在访谈中提到的共同主题和模式，识别影响他们使用 AI 技术的各种因素。同时，我们会在每轮访谈后进行反思与调整，以不断优化我们的访谈问题和研究框架，使之更加符合教师的真实想法与需求。

通过这种方法，我们希望过未来的访谈和深入分析，能够为 STEM 教师提供更多外部的建议和在实践中的指导。最终，我们的目标是提供全面而深入的研究报告，帮助教育管理者、政策制定者以及教师专业发展机构更好地理解和支持 STEM 教育中的 AI 技术应用，为提高教育质量提供数据支持和理论依据。

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人智共生视域下的思维范式转型：构建群智思维

Paradigm Transformation of Thinking in the Perspective of Anthroposophical Symbiosis:

Constructing Group Thinking

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【摘要】强人工智能技术地迭代加速了机器的类人化程度，教育智能体作为第三位“主体元素”介入课堂，教学由教师—学生的双边互动演化为教师—教育智能体—学生多元群体的复杂协同。在新的课堂场域中，群智思维范式是解决人机深度协同、智慧共创的关键。群智思维以教学中多元主体深度协同与持续共创为起点，以共生理论为基础，围绕共生单元、共生模式、共生环境三要素分析主体间的共生共荣关系，从教育观和技术观双重视角审视群智思维的价值意蕴，即主体从“单向遮蔽”转向“具身存在”，人机由“双向博弈”走向“合作共赢”。基于杜威的教育哲学思想，剖析了人智共生的群智思维范式倾向，并诠释其发生机制，以期为智慧课堂中人技关系由“双向博弈”转向“群智共创”的未来发展提供参考和借鉴。
【关键词】群智思维；共生理论；杜威教育哲学思想；人机协同；教育智能体

Abstract: *The iteration of strong AI technology has accelerated the degree of humanoidization of machines, and teaching has evolved from bilateral teacher-student interactions to complex synergies of teacher-educational intelligences-student multiple groups. In the new classroom field, the group intelligence thinking paradigm is the key to solving the human-machine deep synergy and intelligent co-creation. Taking the deep synergy and continuous innovation of multiple subjects in teaching as the starting point, and based on the symbiosis theory, Group Intelligence Thinking analyzes the symbiosis and co-prosperity relationship between subjects, and examines the value implication of Group Intelligence Thinking from the dual perspectives of educational viewpoints and technological viewpoints. Based on Dewey's pedagogy, we analyze the paradigmatic tendency of human-intelligence symbiosis of group intelligence thinking and interpret its occurrence mechanism, in order to provide reference for the future development of human-computer relationship in the smart classroom, which has shifted from “two-way game” to “group intelligence co-creativity”.*
Keywords: Groupthink；Symbiosis theory；Dewey's pedagogy；human-computer synergy；educational agent

1. 研究目的

本研究旨在探讨人智共生视域下教育领域中思维范式的转型问题，提出并构建“群智思维”这一新型思维范式，以应对智能技术深度介入课堂教学所带来的复杂协同挑战。具体研究目的包括以下三个方面：

1.1. 范式解构

通过分析传统思维范式的认知边界与局限性，揭示技术介入课堂后主体关系演变引发思维范式转型的本质，即教育智能体作为第三位“主体元素”介入课堂，进而提出群智思维范式在解决人机深度协同、智慧共创中的关键作用。

1.2. 理论重构

基于共生理论（Bary, 1879）、杜威教育哲学思想（Dewey, 1916）和复杂适应系统理论（Holland,1992），解析群智思维的内涵、理论基础及价值意蕴，结合教育和技术的双重视角，诠释人机协同课堂中教师—教育智能体—学生多元主体间性特征与知识涌现机制。

1.3. 模型建构

阐明人智认知主体在感知协同、推理增强和决策优化三阶段的互动拓扑结构，建立跨模态人智认知互嵌的群智思维概念模型，并通过迭代设计进行模型优化，旨在实现主体间的协同进化与范式级突破。

2. 研究背景

探索人智共生视域下的思维范式转型，不仅是课堂主体多元协同的需要，更是推动教育从"技术赋能"向"思维变革"深层次转型的关键，研究背景包含以下两点：

2.1. 主体升维：从二元对立走向多元共生

2025 年开年火爆世界的 DeepSeek 展现了其超强的思维链和语言推理能力，推动了课堂教学主体由"机器辅助"向"人机共智"的变革（郭蕾蕾，2025）。随着智能技术的加速演进，生成式人工智能在诸多复杂任务中表现出与人类不相上下的心智能力（Hagendorff et al., 2023）。传统"师—生、生—生"人际间双向教学传递，转化为"师—机—生、生—机—生"的人机协同教与学新模式（黄荣怀等，2023）。也就是说，单向主导课堂场域被打破，除了教师和学生，机器也成为了平等的课堂协作伙伴。在主体多元的新型课堂场域中，教师如何基于自身教学经验和教育智能体的辅助实现教学高效化和指导个性化？教育智能体如何基于已有数据库和人类的反馈实现模型优化和交互智能化？学生如何基于教师教学和教育智能体的对话实现知识深化和学习泛在化？综上，多元个体如何优劣互补，形成互利共赢的深度耦合关系是当前人机协同教学的关键(Ericsson et al., 2024)。

2.2. 思维转向：人机协同教学的范式跃升

人机协同教学旨在实现知识习得效能的优化与认知质量的提升，最终构建起兼具系统性与发展性的新型教育范式。关于人机协同教学的研究，宏观层面主要是将新兴技术迁移至课堂教学中，引发教学流程的数字化（廖宏建等，2024）、学习方式的个性化（徐升等，2024）、评价方式的过程化（郑娅峰等，2024）以及教学管理的高效化（刘邦奇等，2021）等。微观层面则聚焦于智能技术介入所带来的教学理念（王一岩等，2024）、教学模式（李海峰等，2024）、教学理论（方海光等，2022）、教学方式（卢宇等，2024）等的革新。缺乏对这些要素产生方式的思考，即教学思维方式。迈克· 富兰 (Fullan, 1993) 曾直接强调教育思维方式对于教育变革的重要性。实质上，当前许多技术应用表面化、欠合理、效果不显著、难以深度融合等"顽疾"长期得不到解决，并非仅仅是因为教师的数字化知识、能力不足，更在于教师的思维范式未能彻底转变。用什么方式去看待教学, 这实际上涉及教与学思维方式的问题。任何教学行为的改变, 任何教学改革的实现,首要的是要实现思维方式的变革（杨鑫，2024）。因此，亟需新的思维范式以适应这一结构性变化。

3. 研究方法

为提升本研究的理论解释力与实践指导价值，搭建了"比较—理论—设计"的三维方法论框架，具体如下：

3.1. 比较研究法

选取认知主体、决策机制、权利结构、伦理风险四个维度（如表 1），对比传统思维范式与群智思维范式的差异，揭示技术介入课堂引发的主体关系演变与认知升级机制，论证群智思维范式提出的合理性和必要性。

表 1 群智思维比较维度

维度	传统思维范式	群智思维范式	比较目标
认知主体	人类中心	人智共生	分析机器如何扩展认知边界
决策机制	线性推理	涌现性机制	验证群智协同是否提升问题解决创新性
权利结构	教师或学生权威	动态角色分配	揭示技术如何重构课堂权利关系
伦理风险	人类责任明确	算法偏见	对比两种范式的伦理脆弱性差异

3.2. 文献研究法

系统梳理共生理论、杜威教育哲学思想、复杂适应系统理论相关文献，从共生性、人本性、涌现性三方面剖析群智思维的内涵、理论基础及价值意蕴（如表 2)，为群智思维范式的理论框架构建提供支撑。

表 2 群智思维理论剖析

理论	特征	核心观点	与群智思维的关联
共生理论	共生性	点共生、间歇共生、一体化共生	解析教师—教育智能体—学生主体间的能量交换与共生共荣关系
杜威教育哲学思想	人本性	以学生为中心	重构课堂协作关系，强调人智良性协同
复杂适应系统理论	涌现性	适应性主体	揭示多主体协同的群智涌现机制

3.3. 基于设计的研究

采用基于设计的研究（Design-Based Research，DBR），研究步骤分为：问题分析与理论建构、干预设计与原型开发、迭代实施与数据收集、模型验证与理论生成，实现模型在感知协同层、推理增强层、决策优化层的三级循环迭代，并在真实教育场景中发展和验证群智思维模型的效应（如表 3）。

表 3 群智思维模型建构

DBR 阶段	核心任务	操作化内容	输出产物
问题分析与理论建构	教学需求诊断 理论框架建立	(a)教育场景中群智思维障碍分析 (b)三维度理论假设构建	初始理论模型 研究问题清单
干预设计与原型开发	分层设计干预 技术原型实现	(a)感知协同层：多模态数据融合机制研究 (b)推理增强层：人智认知互补算法开发 (c)决策优化层：动态权重分配原型构建	操作干预方案 技术原型系统
迭代实施与数据收集	情境任务实施 多源数据采集	(a)真实课堂场景中实验测试 (b)多源异构数据收集与表征	过程性数据集 迭代改进意见
模型验证与理论生成	维度效能验证 理论模型完善	(a)结构方程模型检验三维度的关联性 (b)基于扎根理论的机制解释模型建构	修正理论模型 设计原则框架

4. 现在的研究阶段、初步结果

目前已初步形成理论框架，包括以下两点：

4.1. 界定了群智思维的内涵

在特定教学情境中，由异质性认知主体（教师作为专业引导者、学生作为主动建构者、教育智能体作为认知增强者）通过多模态交互形成的动态认知思维网络，其特征为多元认知协同、涌现性学习机制、迭代范式进化。

4.2. 搭建了群智思维发生机制理论模型

该模型采用横向分层与纵向演进的双维度整合框架，阐释了群智思维从要素整合到范式进化的动态机理(如图 1)。

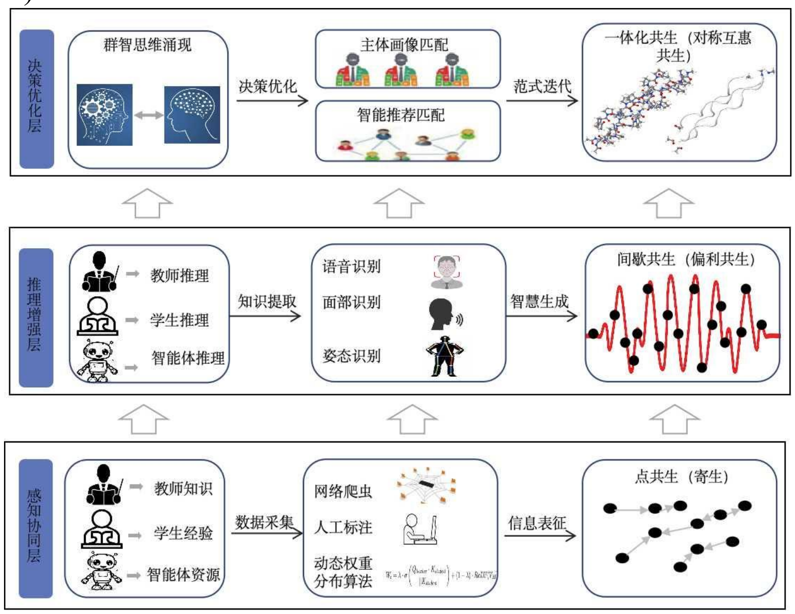

图 1 群智思维发生机制理论模型

5. 下一步将展开的研究工作

接下来将从理论深化和实证探索两方面推进研究工作，具体如下：

5.1. 深化理论探索

对比中西方跨文化视角下群智思维的范式差异，剖析西方思维范式中的个体理性聚合与东方视角下的关系协同作用（Nisbett, 2004），深挖群智思维特征，构建本土化的群智思维理论，以提升理论模型的解释力。

5.2. 推进实证研究

在理论模型的基础上，设计支持群智思维的技术工具，在真实的教学场景中开展实验研究，观察群体协作中的认知演化规律，不断修正模型，最终形成“触发条件—交互过程—涌现结果”的系统化群智思维发生机制理论，使结果具有实践指导价值。

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基于生成式教学智能体的问题提示支架在编程教育中对学生学习效果的影响研究

The Impact of Problem Prompting Scaffolds Based on Generative Pedagogical Agents on Students' Learning Outcomes in Programming Education

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【摘要】 随着智能时代的深入发展，利用生成式人工智能技术（GAI）改善学习效果已经受到学界越来越多的关注。但目前生成式教学智能体（GPA）在学习中的应用效果还未得到充分探究。因此，研究以参与编程教育的 92 名高一学生为研究对象进行为期 6 周的随机对照试验，旨在调查基于 GPA 的问题提示支架工具对学生计算思维、学业表现、元认知能力的影响。研究发现，基于 GPA 的问题提示支架能够促进学生的计算思维、学业表现与元认知能力。文章深入分析和讨论了研究结果，旨在为 GPA 融入教学提供证据参考。
【关键词】 生成式教学智能体；问题提示支架；编程教育；计算思维；元认知

Abstract: *The use of generative artificial intelligence technologies to improve learning has received increasing attention from the academic community, but the effectiveness of generative pedagogical agent in learning has not yet been fully explored. Therefore, the study conducted a 6-week randomized controlled trial with 92 senior high school students participating in programming education with the aim of investigating the effects of a GPA-based question prompt scaffolding tool on students' computational thinking, academic performance, and metacognitive abilities. The study found that the GPA-based question prompt scaffolding was able to promote students' computational thinking, academic performance, and metacognitive abilities. The article analyzes and discusses the results of the study, aiming to provide evidence to inform the integration of GPA into teaching and learning.*
Keywords: generative pedagogical agent, question prompt scaffolding, computational thinking, metacognition

1.前言

21 世纪的学习者应具备创新能力、批判性思维、问题解决能力(Rehman et al., 2023)。在计算机科学领域，编程教育被认为是培养创造力、计算思维的首选方法，对于培养解决问题的能力和批判性思维具有至关重要的作用(Mathew et al., 2019)。然而，有研究表明，学生在编程学习过程中也可能会遇到问题，如缺乏相关技能或无法获取关键资源(Tom, 2015)，而这种挑战或许会对学生学习产生负面影响。对此，有必要为学生的编程学习提供全面支持，如设计教学支架帮助学生整理思维、设计算法、顺利地参与问题解决的过程(Sun et al., 2021)。

在智能技术的深入推进下，生成式人工智能技术（GAI）近年来受到学界广泛关注，其基于自然语言支持的对话能力使其在教学与反馈中具有良好应用潜力，为学生提供个性化和便捷的学习体验(Guo et al., 2023)，这为解决编程教育中存在的问题提供了新的思路。已有研究证实人工智能支持工具和环境的优势可以有效地提高学生的计算思维技能、编程自我效能感和上课的积极性(Yilmaz & Yilmaz, 2023)。而纵观目前关于 GAI 的研究，大多集中在单一 GAI 支持的教育对学生学习效果的影响，或是集中在教育应用框架、风险及应对建议(Yusuf et al., 2024)等理论层面，鲜有学者将研究聚焦在面向学生个人特征设计智能体支持学习过程，以探讨基于生成式人工智能技术的智能体对学生学习效果的影响。而学生在学习过程中具有个性差异，基于学生

知识水平、个人特征等进行针对性反馈仍至关重要(Keuning & van Geel, 2021)。基于此，本研究立足于高中编程课程，旨在调查基于 GAI 的智能体辅助编程教育对学生计算思维、学业成绩与元认知能力的影响。

2.基于生成式教学智能体的问题提示支架设计

2.1 生成式教学智能体设计

生成式教学智能体(Generative Pedagogical Agent,简称 GPA)是基于 GAI 创建的具有教学功能的智能体，使用预设的指令和教学材料引导 GAI 实现在指定学科教学中支持学生学习(张渝江 et al., 2024)。主要是通过提示词和知识库内容结合来增强 GAI 以展现更好的教学行为和内容输出。研究参考在 Chee 的提示词设计基础上进行改编(Ng & Fung, 2024)，如表 1 所示改变后的提示词设计旨在从学习者那里引出特定信息或提供有针对性的建议。输入通常包括学习者特定的数据，例如当前的知识水平、面临的挑战和教育目标。输出是定制的建议或解释，指导学习者完成个性化的学习之旅。

表 1 生成式教学智能体设计

通用设计	主题/背景	介绍本节课程的主题或者背景信息
	学习目标	根据布鲁姆的教学目标分类理论设计知识、理解、应用、分析、综合、评价六个层次学习目标
个性设计	初步评估	[提示]：根据学习者当前对[主题]的理解，评估他们的知识水平并建议他们接下来应该学习的概念，以掌握[主题]; [输入]：学习者当前对给定主题的理解或表现; [输出]：根据学习者当前知识水平定制建议概念的列表;
	澄清	[提示]：学习者认为[主题]中的哪些具体领域具有挑战性？请提供详细信息; [输入]：学习者对他们认为困难的领域的反馈; [输出]：对具有挑战性的领域的详细描述，将用于调整学习路径;
	解释	[提示]：解释为什么在[概念 B]之前学习[概念 A]有利于学习者对[主题]的理解; [输入]：学习路径中的概念序列; [输出]：详细说明建议序列的解释;

2.2 问题提示支架设计

在 GAI 应用过程中，具体、明确的提问更能激发其生成高质量的回答(Chen et al., 2024)。然而，大多数学生缺少该方面的元认知能力。一个可能的解决方案是教师为学生提供更多关于以适当方式查询 ChatGPT 的策略的指导。其中，问题提示支架是一种可能的方法，它支持学生将更好的提示表述为问题(White et al., 2023)。本研究设计的问题提示支架在 5W(戴岭 et al., 2023)（Who—分配模型扮演的角色，What—设置模型执行的任务或附上示例，When—确定模型完成任务的时间，Where—赋予提示的位置或场景，Why—告知提示的理由、动机或目标）、5S(Set the Scene、Be Specific、Simplify your Language、Structure the Output、Share Feedback)(Tassoti, 2024)提示的基础上，融合不良结构问题解决步骤（问题表述、生成解决方案、提出理由、监控和评估）及其提示(Ge & Land, 2004)进行改编，设计如图 1 所示。

图 1 问题提示支架

3.研究设计

3.1 研究对象

本研究在中国山西省某高中高一年级《信息技术》课程中随机选择了两个平行班，共 92 名学生，学生年龄 15-16 岁之间。其中，实验班为面向生成式教学智能体的问题提示支架组，共学生 47 名，对照组为面向生成式教学智能体的传统教学组，共 45 名学生。

3.2 研究流程

整个实验实施过程如图 2 所示，教学活动持续 6 周，每周 1 课时（50 分钟）。正式实验开始前，两个班的学生进行计算思维、Python 知识测试和元认知能力的前测调查。同时，授课教师向所有学生介绍如何基于上述 GPA 框架设计符合个人特征的 GPA，并向实验组学生介绍问题提示支架如何使用，两组学生分别结合 ChatGPT-4 进行练习。之后，对照组与实验组学生同时开展 Python 编程程序设计的学习活动，两组学生涉及相同的学习内容和任务，实验组学生在采用基于 GPA 的问题提示支架，对照组采用基于 GPA 的传统学习方式。为防止学生认知懒惰，教师要求在学生完成算法设计后再应用基于 GPA 的问题提示支架进行后续交互。教学活动结束后，两组学生进行计算思维、Python 知识测试和元认知能力的前测调查。

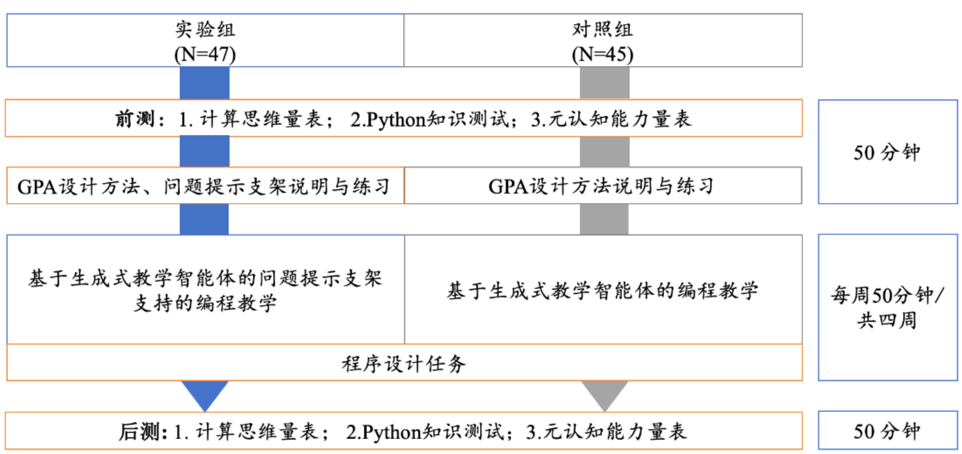

图 2 实验流程图

3.3 研究工具

3.3.1 计算思维量表

研究选用 Korkmaz 等人开发的计算思维测评量表(Korkmaz et al., 2017)，通过前后测试评估学生计算思维的变化。该量表包含创造力（1-8 题）、问题解决（9-14 题）、算法思维（15-20 题）、批判思维（21—25 题）和协作能力（26—29 题） 5 个子维度，采用李克特 5 级量表进行评分，分数越高，学生的计算思维能力越高。整个量表的 Cronbach's α 值为 0.931，分维度依次为 0.887、0.847、0.912、0.884、0.903，均大于 0.7 表明该量表具有较好信度。

3.3.2 Python 知识测试试卷

研究基于 Python 预测试评估学生的知识水平，结合高中教材数据与计算章节的综合题和往年的信息技术考试题，由研究人员与信息技术教师协商共同编织。Python 知识测试来自实验期间涵盖的材料，由完全客观的 20 个选择题组成，涵盖 Python 语言的基础知识，重点是循环结构、多分支结构和基本编程语法。为确保测试结果的可靠性，研究对试题提供了明确的说明，以避免任何误解。

3.3.3 元认知能力量表

研究使用 Sperling 等人提出的元认知能力量表(Sperling et al., 2002)，该量表包括元认知知识（1-6 题）和元认知调节（7-18 题）两个维度，采用李克特 5 级量表进行评分。该量表的 Cronbach's α 值为 0.901，分维度依次为 0.783、0.868，均大于 0.7 表明该量表具有较好信度。

4.研究结果

4.1 基于 GPA 的问题提示支架对学生计算思维的影响

研究采用独立样本 T 检验，对两个组学生进行实验前的计算思维进行分析，经分析可知，实验组与对照组的计算思维不具有显著性差异(p=0.309>0.05),并且在五个具体的分维度也不具有显著性差异。说明实验开始前，实验组和对照组的计算思维水平基本相同，不存在差异。同样，研究检验了实验结束后实验组与对照组的计算思维水平。独立样本 T 检验的结果如表 2 所示，计算思维水平表现出显著差异(t=0.80, p=0.040<0.05)，并且在算法思维(p=0.020<0.05)维度上存在显著性差异，但在其他分维度不具有显著性差异。

此外，研究对测试前和测试后的数据进行了配对样本 T 检验，以评估计算思维是否存在差异。

表 3 的结果表明，实验组的计算思维能力显着提高。基于生成式教学智能体的问题提示支架有助于增强计算思维，在计算思维的各个维度上显示出显著的提升。在对照组中，学生主要提高了算法思维。

表 2 学生实验后计算思维的比较

	实验组		对照组			
	M	SD	M	SD	t	p
创造力	3.92	0.56	3.76	0.49	1.47	0.78
问题解决	3.58	0.68	3.40	0.67	1.24	0.88
算法思维	3.37	0.90	3.28	0.62	0.56	0.02*
批判思维	3.72	0.65	3.57	0.61	1.10	0.58
协作能力	4.19	0.73	3.96	0.66	1.54	0.14
计算思维	3.74	0.56	3.58	0.47	0.80	0.04*

*p<0.05.

表 3 学生测试前后计算思维差异

	实验组			对照组		
	M	SD	t	M	SD	t
创造力	3.68	0.61	2.23*	3.58	0.55	2.04*
	3.92	0.56		3.76	0.49	
问题解决	3.29	0.74	2.36*	3.09	0.72	2.48
	3.58	0.68		3.40	0.67	
算法思维	3.27	0.78	0.83*	3.27	0.57	0.08*
	3.37	0.90		3.28	0.62	
批判思维	3.47	0.70	2.09*	3.43	0.63	1.36
	3.72	0.65		3.57	0.61	
协作能力	3.73	0.85	3.25*	3.70	0.66	2.10
	4.19	0.73		3.96	0.66	
计算思维	3.48	0.54	2.71**	3.40	0.44	2.22
	3.74	0.56		3.58	0.47	

*$p<0.05$; **$p<0.01$.

4.2 基于 GPA 的问题提示支架对学生 Python 知识测试成绩的影响

研究使用协方差分析检查两组学生之间 Python 学习表现的差异，模型中包含协变量（预测试表现）和自变量（实验方法）。排除预测试的影响后，观察到两组学习成绩存在显著差异（F =8.50，$p<0.01$）。之后，研究对测试前和测试后的数据进行了配对样本 T 检验，以评估 Python 知识测试成绩是否存在差异。表 4 的结果表明，与不使用任何脚手架的对照组相比，使用面向生成式教学智能体的问题提示支架的实验组学生取得了更高的学习成绩。

表 4 学生测试前后学习测试成绩差异

	M	SD	M	SD	t
实验组	72.87	17.15	76.86	20.69	1.27*
对照组	66.83	21.37	74.33	12.64	2.69

*$p<0.05$.

4.3 基于 GPA 的问题提示支架对学生元认知能力的影响

研究对两个班级的前后测数据进行配对样本 T 检验，以探讨基于 GPA 的问题提示支架是否能够增强学生的元认知能力，结果如表 5 所示。从中可以看出，经过教学实践后，实验组学生的元认知能力（$p = 0.018$）有显著所提高。此外，实验班学生在元认知知识维度上存在极显着差异（$p < 0.01$），在元认知调节维度上存在显着差异（$p =0.012$），表明结合 GPA 的问题提示支架的编程教学实践可以提高学生的元认知能力。此外，对照组学生在元认知知识维度上有显著性提升（$p = 0.03$）。

表 5 学生测试前后元认知能力差异

	实验组			对照组		
	M	SD	t	M	SD	t
元认知知识	3.63	0.57	2.23**	3.63	0.55	1.89*
	3.93	0.61		3.78	0.68	
元认知调节	3.55	0.51	1.09*	3.48	0.51	2.32
	3.64	0.64		3.64	0.65	
元认知能力	3.58	0.50	2.15*	3.53	0.48	2.66
	3.74	0.60		3.69	0.63	

*$p<0.05$；**$p<0.01$.

5.讨论

5.1 基于 GPA 的问题提示支架能够显著促进学生的计算思维水平

在本研究中，实验组相较于对照组表现出了更高水平的计算思维，可以认为，基于 GPA 的问题提示支架能够显著促进学生的计算思维，这与 Gong 等人的研究结果一致(Gong et al., 2024)。其原因可能在于，计算思维的培养主要依托于编程任务，按照问题提示支架的步骤为学生提供元认知支持。具体来看，开发程序时，学生根据教师提供的支架分析程序语句、补充完善自己的程序结构和程序语句；调试程序时，学生可以进一步分析 GPA 反馈的程序内容与相关解释，进而修正自己的错误。此外，面对复杂的编程问题，如果将其作为一个整体来寻找解决方案，学生可能会产生畏惧心理，相较于对照组学生，基于 GPA 的问题提示支架帮助学生将一个复杂的编程任务进行拆分，为明确的编程任务和编程语句提供支持，学生可以根据 GPA 反馈的编程任务提示深度加工编程知识和概念，借助这些提示对编程过程中出现的问题进行校对，并在反复操作和试错的过程中积累程序编写的经验(Molenaar et al., 2010)，以此不断强化对编程语言的理解，加深对计算概念和计算实践的掌握。

5.2 基于 GPA 的问题提示支架能够提升 Python 知识测试成绩

对学生后测 Python 知识测试结果的分析表明，实验组学生的成绩获得了更显著的提升。可以认为，基于 GPA 的问题提示支架能够提升 Python 知识测试成绩，这与 Malik 等人的研究结果相似(Malik et al., 2022)。这可能是由于学生与 GPA 互动能够获得个性化支持与反馈，帮助他们按照自己的节奏进步并提高编程技能。具体来看，具有明确学习目标与学习者个人特征的 GPA 能够为学习者解决程序设计过程中的常见编程错误、语法和语义等内容提供具体的反馈与解释。此外，GPA 能够激发有趣的学习体验来满足学生的需求，缓解了学生因长时间等待反馈而产生的心理压力，从而增强学生对技术易用性和有用性的感知，改善了学生的学习体验，为有效促进学生学习成绩的提升提供可能(Muñoz-Carril et al., 2021)。

5.3 基于 GPA 的问题提示支架能够显著促进学生元认知水平的发展

相较于对照组，实验组表现了更高的元认知能力，在元认知知识和元认知调节两个维度具有显著性提升。可以认为，基于 GPA 的问题提示支架能够显著促进学生元认知水平的发展，这与 Abdul-Rahman 等人的研究结果一致(Abdul-Rahman & Du Boulay, 2014)。究其原因，一方面，GPA 采用提示学习与人类反馈相结合的训练方式，具有基于用户提问进行个性化知识生产的能力，能够根据提问提供多轮次、流畅、自然的回答。另一方面，问题提示支架为 GPA 提供具体的背景、明确的问题边界、连贯的上下文、指定形式的反馈内容，即提供了一种明确形式的元认知指导，帮助学习者能够轻松地使用和内化，特别是帮助学习者回忆和激活先验知识来促进思想的阐述、明确解决问题的过程和相应的提问策略(Xie & Bradshaw, 2008)。同时，GPA 在对比、评估学生生成的问题解决方案后生成的反馈能够增强学生对任务的理解，这种反思性提示能够促进学生元认知水平的发展(Sijmkens et al., 2023)。此外，研究发现问题提示支架可以促进学生讨论的深度，对照组的学习者在不使用问题提示时很少会主动提出问题或深入讨论他们的想法和观点，导致无法检查改进点以及在解决方案中出现问题时准备替代方案来进行监控和评估(Ge & Land, 2004)。

6.总结与展望

随着人工智能教育的深入发展，生成式人工智能近年来受到学界越来越多的关注。本研究探讨了基于 GPA 的问题提示支架在编程教育中的应用效果，发现其能够显著促进学生的计算思维与知识测试成绩，并能够激发学生产生更多元认知知识与元认知调节行为。总体而言，研究为基于 GPA 的问题提示支架与学生学习的融合应用提供了证据参考。但也还存在一定局限性，如样本量较少、实验周期短、学习者的年龄和专业分布单一等。未来的研究将进一步突破上述这些限制，创新 GPA 在教学模式、策略等方面的融合应用，并从长周期、多视角对其应用效果进行分析。

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