Journal of Science Education Vol.26 n° 1 2025

Journal of Science Education

ISSN 0124-5481

Designing Protective Suits for Manned Lunar Landing: A STEM Course Enhanced by the Pedagogical Agent

Hongjian Li[a], Jinghan Ren[b*]

[a] *Beijing Bayi School, Beijing 100080, China;*
[b] *Faculty of Education, Beijing Normal University, Beijing 100875, China*

[*]*Corresponding Author*

ARTICLEINFO

Keywords:
STEM
Aerospace Education
Pedagogical Agent
Educational Artificial Intelligence
Physics Education

ABSTRACT

This study explored the integration of the Pedagogical Agent (PA) into STEM curricula through a case study on designing protective suits for the manned lunar landing. Grounded in the 6E learning model and real-world problem-solving scenarios, the course engaged high school students in interdisciplinary inquiry, combining physics, engineering, and materials science knowledge. This teaching model fostered human-machine collaboration by embedding PA as an intelligent learning companion to support students' personalised learning, scientific literacy, and higher-order skills. Results showed that in human-machine collaborative teaching and learning scenarios, PA could assist students in expanding their knowledge boundaries and take on repetitive and routine tasks, thereby freeing teachers to focus on higher-level instructional activities. Teachers, in turn, should devote their efforts to deep conceptual explanations, emotional support, and creative pedagogy to cultivate students' higher-order skills. This study proposed strategies to balance the respective advantages of teachers and AI, promoting the construction and practical implementation of a human-centred and intelligent STEM curriculum system.

1. Introduction

As conceptions of science education evolve, the notion of scientific inquiry is increasingly being subsumed under the broader framework of scientific practices (Abd-El-Khalick et al., 2004). The Next Generation Science Standards (NGSS) advocate for instructional goals structured around three dimensions: science and engineering practices, disciplinary core ideas, and crosscutting concepts, emphasising the deep integration of science, technology, and engineering. In parallel, the Ministry of Education of the People's Republic of China incorporated inquiry-based practice as a central component of science education in its 2022 Curriculum Program and Standards for Compulsory Education, highlighting a progression from everyday life to inquiry, and from inquiry to practice, thereby promoting interdisciplinary integration. The 2024-2035 master plan on building China into a leading country in education further underscores this trajectory by calling for establishing mechanisms to identify and cultivate innovative talent and advocating the application of Artificial Intelligence (AI) to drive educational reform. These policies collectively support the transformation of engineering-oriented STEM (Science, Technology, Engineering, and Mathematics) education through Artificial Intelligence. In STEM education, engineering design not only bridges scientific knowledge with real-world challenges but also plays a critical role in cultivating students' higher-order abilities, including innovative thinking, critical thinking, and complex problem-solving. Globally, increasing emphasis is placed on STEM education in primary and secondary schools to foster well-rounded talents capable of meeting future societal demands (Tavdgiridze et al., 2024). China, in turn, continues to localise STEM curricula and practices, aiming to develop a model of STEM education with distinct Chinese characteristics.

As a core component of STEM education, engineering design involves proposing systematic solutions to real-world problems through decomposition, combination, and abstraction (Lin et al., 2021). Rooted in authentic problem-solving, this approach promotes interdisciplinary integration and the development of engineering thinking, serving as a critical pathway for fostering scientific literacy. Recent advances in AI have enabled the integration of the Pedagogical Agent (PA) into STEM curricula, offering novel solutions to long-standing challenges such as limited authenticity in traditional learning scenarios and insufficient personalised support. The Pedagogical Agent (PA) is a virtual assistant based on artificial intelligence technology that can provide personalised learning support and feedback based on user input to meet different teaching objectives. These agents integrate big data analytics, natural language processing, and multimodal interaction to autonomously perceive and interpret learning environments, dynamically model learners' cognitive states, and perform reinforcement learning based on user feedback, thereby offering precise scaffolding to support learners in accomplishing complex learning tasks.

This case study adopted the 6E (Engage, Explore, Explain, Engineer, Enrich, and Evaluate) Learning by DeSIGN™ model to construct a real-world problem scenario centred on a manned

Accepted February 2025, Available online 30 July 2025

lunar landing mission, thereby fully embedding the core processes of engineering design. Furthermore, by integrating PA into instruction, a human-machine collaborative teaching model is established, in which students engage in immersive dialogue with agents under the guidance of teachers. This mode of human-machine co-creation not only enhances the efficiency of iterative design and fabrication but also effectively promotes the development of students' scientific literacy and higher-order skills. The approach provides a practical paradigm and valuable reference for cultivating innovative talent in the era of intelligent education.

2. Instructional Objectives and Unit Instructional Design

2.1. Instructional Objectives

This unit is designed in alignment with the national curriculum standards and the cognitive characteristics of first-year high school students, with a focus on developing students' core competencies in physics. The teaching objectives are structured across four dimensions: physical concepts, scientific thinking, scientific inquiry, and scientific attitudes and responsibility.

- Physical Concepts: Students will observe and describe the properties of rays through cloud chamber experiments, understand the physical nature of radiation, and grasp the basic principles of shielding and absorption as applied to the design of protective suits.
- Scientific Thinking: Students will learn to deconstruct complex design tasks, such as material selection and structural optimisation, into manageable subproblems, formulate systematic solutions, and construct physical models to analyse key factors influencing protective suit design based on experimental data.
- Scientific Inquiry: Students will independently carry out experiments, record and analyse data, and iteratively improve their suit design proposals, offering evidence-based suggestions for optimisation.
- Scientific Attitudes and Responsibility: Real-world and task-driven scenarios are employed to stimulate students' interest in science, foster their spirit of exploration, promote teamwork and innovation, and enhance their awareness of the life-saving implications of protective suit design for astronauts, thereby strengthening their sense of social responsibility.

This unit is centred around the core task of designing key components of functional spacesuits and integrates interdisciplinary knowledge from physics, chemistry, materials science, and engineering design. Through this interdisciplinary approach, the unit broadens students' perspectives and fosters their capacity to apply knowledge comprehensively in addressing complex real-world challenges.

2.2. Unit Instructional Design

The instructional design of this unit is grounded in the 6E model, an extension of the traditional 5E model that incorporates engineering design principles. The 6E model comprises six phases: Engage, Explore, Explain, Engineer, Enrich, and Evaluate (Chen & Liu, 2025). It emphasises the application of knowledge through real-world tasks, guiding students toward independent exploration and collaborative learning in STEM contexts to enhance their knowledge transfer and problem-solving abilities.

3. Instructional Implementation: Lesson 2. Key Explorations from Theory to Practice

3.1. Learner and Content Analysis

First-year high school students have acquired foundational knowledge in physics, including mechanics, thermodynamics, and electromagnetism, and possess a preliminary understanding of the discipline. However, they have limited experience in applying this knowledge to real-world engineering problems, such as spacesuit design, and require further support in transferring theoretical understanding to complex, authentic contexts. Although students are exposed to interdisciplinary topics such as materials science and life support systems, their knowledge structures remain fragmented. There is an urgent need to integrate multidisciplinary knowledge to help students construct a coherent cognitive framework for understanding and solving problems related to spacesuit design. In terms of scientific practice, students have basic experimental skills but need further development in areas such as experimental design, data analysis, and critical interpretation of results. Many students exhibit a strong interest in space exploration and are particularly curious about how spacesuits function under extreme environmental conditions. They are eager to validate theoretical concepts through hands-on experiments and to strengthen their scientific inquiry and engineering practice capabilities.

Students have developed a foundational understanding of the project theme after the initial lesson in the unit "Lesson 1: Project Initiation", which includes group formation, project background introduction, key task identification, and preliminary knowledge acquisition. Many students have prior experience with group collaboration and project-based learning through earlier coursework or extracurricular activities. In Lesson 2, instruction begins by revisiting fundamental physical concepts and guiding students to build a systematic understanding of the principles underlying spacesuit design. Scenario-based learning, collaborative group work, and experimental tasks are employed to facilitate the transfer of theoretical knowledge into practical application. Throughout this process, the teacher plays a crucial guiding and scaffolding role—helping students clarify project objectives, coordinate group responsibilities, and promote the development of core disciplinary competencies.

3.2. Teaching Process and Instructional Activities

Building on the above analysis, this case takes the question "How can we design protective suits for the manned lunar landing?" as the central driving task. Leveraging the 6E model, it systematically fosters students' core physics literacy across four dimensions: physics concepts, scientific thinking, scientific inquiry, and scientific attitudes and responsibility.

- Scenario-Driven Engagement and Interest Stimulating: This phase aims to spark student interest through real-world scenarios and multimedia materials. The teacher begins by presenting recent video footage of space environments and missions to illustrate the importance of spacesuits. The core task—designing an optimal protective solution for lunar extravehicular activities—is then introduced. Students reflect on the functions of spacesuits under extreme conditions, laying a motivational foundation for deeper exploration.
- Knowledge Sharing and Problem Focus: Students present their prior research on radiation in the form of posters, focusing on types, sources, and impacts on spacesuit design (see Figure 1). The teacher uses scaffolding questions to guide discussions and ensure all groups articulate their findings clearly. Group presentations cover topics such as solar radiation and cosmic rays, their biological hazards, and their implications for materials and shielding. Peer discussion and teacher feedback deepen conceptual understanding and help students begin applying this knowledge to real-world engineering tasks.
- Topic Selection and Project Planning: In this phase, student groups refine their research focus under teacher guidance. Each group selects a specific sub-topic related to radiation protection, balancing shared themes and differentiated directions. The teacher provides iterative feedback to support students' preliminary plans. Students then formulate project plans,

Accepted February 2025, Available online 30 July 2025

outlining objectives, timelines, and responsibilities, thereby improving project organisation and learning autonomy.

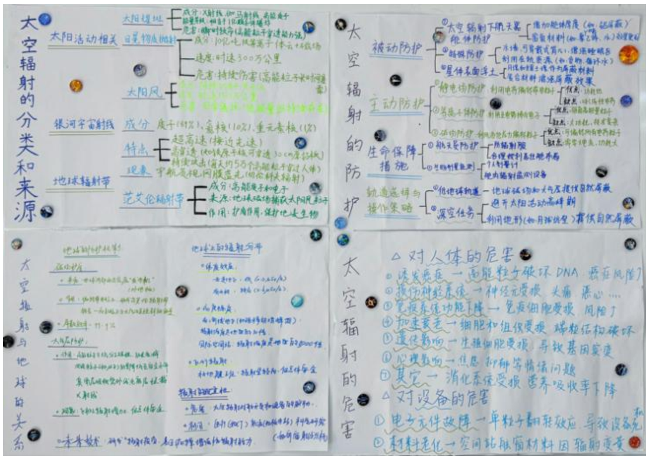

Figure 1. Student poster

- Element Organisation and Creative Ideation: The teacher introduces pre-trained PA to support systematic knowledge construction. After explaining the components, functions, and materials of spacesuits, the teacher guides students in using the PA to map key design elements. Through collaborative brainstorming, students generate visual diagrams categorising design elements and discussing their protective functions. Constraints such as mobility, thermal regulation, and structural integrity are analysed to inspire innovative thinking.

Figure 2. Geiger counters

- Experimental Practice and Reflective Improvement: Hands-on experimentation helps students connect theory with practice. The teacher demonstrates how to use Self-made cloud chambers and Geiger counters (see Figure 2), emphasising safe experimental operation. Students conduct experiments to detect radiation, collect and analyse data, and discuss implications for spacesuit design (see Figure 3). In group discussions, students reflect on experimental challenges and solutions. Finally, the teacher concludes the lesson by presenting a design workflow diagram, helping students transition from experimentation to engineering design.

实验任务单：

	烟雾报警器放射源辐射				
辐射剂量率（μSv/h）	30s	60s	90s	120s	平均值
用A4纸遮挡30s后的辐射剂量率	1张	2张	3张	4张	
是否观察到射线					
射线特征描述（长度，粗细，直/弯曲等）					
根据任务单中的图例推测粒子类型					
射线图像拍照录像留存					

安全操作，注意安全

1.利用云室观察射线。

2.用盖格计数器进行下辐射剂量的探测。

思考：云室和盖格计数器在宇航服设计中可以有什么作用?

Figure 3. Experiment report

3.3. Instructional Technologies

- Low-Cost Self-made Experimental Teaching Aids: Students construct cloud chambers using affordable materials to visualise the paths of charged particles, translating abstract radiation concepts into observable phenomena. The Americium-241 radiation source used is low-activity and meets secondary school safety standards under teacher supervision. The experiment integrates both physics (radiation dose) and biology (health impact), aligning with STEM's interdisciplinary approach. Self-study guides further support students' learning (see Figure 4).

Figure 4. Self-made cloud chambers

- Educational Artificial Intelligence (EAI): The PA, built on a curated knowledge base provided by the professional physics teacher and developed by a third party, supports knowledge retrieval, experimental inquiry, and learning feedback (see Figure 5). It offers contextual explanations on radiation, materials, and protective clothing design before, during, and after the course. While PA fosters students' personalised learning, the teacher retains control over teaching objectives and progress, taking the lead in instructional evaluation and feedback. To maintain students' learning focus, PA's responses are scoped to relevant content.

Figure 5. The Pedagogical Agent

Accepted February 2025, Available online 30 July 2025

- iPad Integration: The iPad serves as the primary interface for interacting with the PA. It provides access to learning resources, supports experimental data collection and analysis, and assists in project management. Real-time data synchronisation enables teachers to monitor students' progress and adjust instruction dynamically.

3.4. Instructional Assessment

Instructional Assessment combines formative and summative methods, focusing on students' ability to apply and transfer knowledge in complex real-world problem-solving contexts rather than solely assessing final products. The assessment tools include:

- Self-evaluation Forms: Students reflect on their learning progress and challenges.
- Peer-evaluation Forms: Group members assess one another's contributions in terms of communication, teamwork, and problem-solving.
- Classroom Observation Forms: Teachers document students' performance in experiments and group tasks, focusing on cognitive processes and collaboration.
- Project Evaluation Rubrics: Teachers assess learning outcomes across dimensions such as knowledge integration, experimental design, data analysis, and project planning.

The evaluation framework centres on core physics learning competencies. It adopts diverse assessment methods to provide timely feedback, guide instructional adjustments, and reflect the diagnostic and motivational functions of effective assessment.

4. Conclusion

This case study adopted "protective clothing design" as a thematic context to promote STEM knowledge integration and inquiry-based learning, encouraging students to engage in deep thinking and develop problem-solving and knowledge transfer skills, which offered practical strategies for cultivating higher-order thinking and scientific literacy. STEM courses empowered by the Pedagogical Agent provide students with a more adaptive and interactive learning environment, facilitating their knowledge acquisition, cognitive development, and emotional growth. This allows students to enjoy the learning process and comprehensively enhance their core literacy and lifelong learning abilities to address future societal challenges.

As "super teaching assistants", educational AI systems demonstrate significant advantages in knowledge coverage and information processing efficiency, but also face challenges such as misinformation and hallucinations persisting. Teachers, as bearers of human wisdom, remain irreplaceable in terms of in-depth explanations and emotional support for students. The key to human-machine collaboration is to fully leverage the complementary strengths of humans and machines to create a new form of hybrid intelligence that extends rather than replaces human intelligence. In human-machine collaborative teaching and learning scenarios, PA can offer tool-based support for students' learning and manage repetitive instructional tasks, thereby freeing teachers to focus on higher-level educational responsibilities. Teachers, on the other hand, should focus on delivering deep conceptual understanding, emotional guidance, and inspirational support, whose role should shift from knowledge transmitters to learning facilitators and technology integrators, cultivating students' critical thinking and creative inquiry skills. Finally, the intelligent transformation of education must also address pressing ethical concerns. Legal and regulatory gaps highlight the need for robust safeguards to protect data privacy, uphold educational humanism, and ensure the safe and equitable use of AI technologies. Future research should explore the mechanisms underlying the deep integration of PA in STEM education, particularly in reshaping knowledge production, instructional design, and evaluation models, thus advancing the construction and practical implementation of intelligent and student-centred STEM curriculum systems.

Acknowledgements
This work was supported by A Practical Study on Cultivating Students' Scientific Literacy through Project-Based Activities: Taking the "Lunar Electromagnetic Fortress" Project-Based Course as an Example (CECA22140).

References

Abd-El-Khalick, F., Boujaoude, S., Duschl, R., Lederman, N. G., Mamlok-Naaman, R., Hofstein, A., ... & Tuan, H. L. (2004). Inquiry in science education: International perspectives. *Science education, 88*(3), 397-419.

Chen, J. C., & Liu, C. Y. (2025). Developing an Interdisciplinary Hands-On Learning Activity With the 6E Model to Improve Students' STEM Knowledge, Learning Motivation and Creativity. *Journal of Computer Assisted Learning, 41*(3), e70031.

Lin, K. Y., Wu, Y. T., Hsu, Y. T., & Williams, P. J. (2021). Effects of infusing the engineering design process into STEM project-based learning to develop preservice technology teachers' engineering design thinking. *International Journal of STEM Education, 8*, 1-15.

Tavdgiridze, L., Didmanidze, I., KHASAIA, I., SHEROZIA, N., DOBORDGINIDZE, D., AKHVLEDIANI, D., & AKHVLEDIANI, Z. (2024). STEM teaching in contemporary education. *Challenges to National Defence in Contemporary Geopolitical Situation, 1*(1).

Accepted February 2025, Available online 30 July 2025