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A Science Experiment Platform Integrating AI Tutors in a Head-Mounted Display Augmented Reality Environment

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Abstract: Lab experiment is increasingly emphasized in science education to enhance students' scientific inquiry capabilities. This study developed a science experiment environment integrating Head-Mounted Display Augmented Reality (HMD AR) with an AI tutor to assist junior high school students in understanding the imaging principles of convex lenses. Preliminary results indicated significant improvements in students' optical conceptual test scores. Additionally, guidance from the AI tutor promoted students' reflective observation during lab experiments. However, students' active interaction with the AI tutor remains limited and requires further enhancement.

Keywords: Augmented Reality, AI tutor, lab experiment, generative AI

1. Introduction

Recent trends in science education have increasingly emphasized lab experiment through hands-on experiments and observations to enhance students' conceptual understanding. Gire et al. (2010) indicated that hands-on experiences significantly deepen students' comprehension of physical concepts. However, Hofstein and Kind (2011) highlighted the necessity of promoting higher-order thinking processes during science experiments, rather than focusing solely on practical manipulations. Although augmented reality (AR) technologies support the comprehension of abstract concepts, students often become overly reliant on virtual guidance, neglecting reasoning processes (Radu & Schneider, 2023). The integration of Head-Mounted Display (HMD) AR with AI tutoring systems is a relatively new research area with promising potential for providing real-time instructional support (Gunturu et al., 2024). Thus, this study developed an environment combining HMD AR and AI tutors to explore its effects on junior high school students' learning outcomes in scientific experiment.

2. System Design

The proposed platform consists of three main components, as illustrated in Figure 1 and the environment was shown in Figure 2:

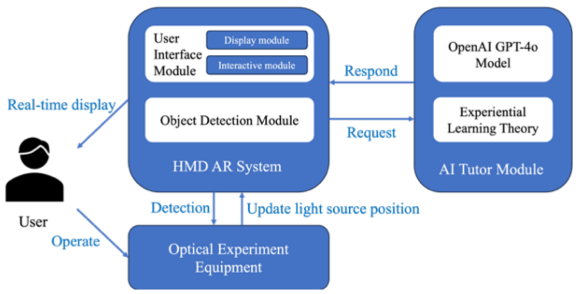

Figure 1. System architecture

2.1 Optical Experiment Equipment

This equipment includes a convex lens, a movable light source, and a movable paper screen. The convex lens is fixed to the primary axis of the experiment equipment, while students manually adjust the positions of the light source and paper screen to observe different optical phenomena and resulting image properties (e.g., image size and position).

2.2 HMD AR System

The system is composed of two subsystems: an Object Detection Module and a User Interface Module. The Object Detection Module continuously tracks the position of the light source and instantly updates the positioning of virtual information precisely overlaying the physical equipment. As depicted in Figure 2, the User Interface Module visually presents real-time virtual guidance, including a virtual optical axis, paths of the light rays, and image formation points. Through interactive buttons, students can toggle virtual ray displays, initiate dialogues with the AI tutor, and adjust virtual information display modes, enhancing their overall learning experience.

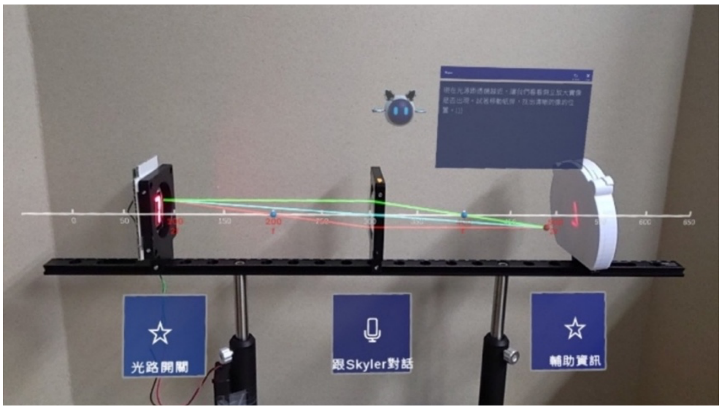

Figure 2. User interface

2.3 AI Tutor Supporting Experiential Learning

This component comprises an AI Tutor Module based on experiential learning theory. Based on Kolb's (1984) experiential learning theory, the AI tutor guides student interactions through a four learning stages: Concrete Experience, Reflective Observation, Abstract Conceptualization, and Active Experimentation. By monitoring students' experiment behaviors and progress, the AI tutor dynamically provides suitable operational hints and guiding questions tailored to each learning stage. For instance, it encourages students to explore various positions of the light source, guides focused observations on critical ray paths, and prompts them to formulate specific inquiry questions during the observation process.

The AI tutor establishes a human-computer interaction mechanism by invoking the GPT-4o model. It utilizes professionally designed prompts tailored to the specific experiment context, enabling the AI tutor to promptly respond to students' experiment activities and learning needs, while providing instructional guidance and reflective questions that facilitate deeper thinking in the experiment. Additionally, this module captures students' voice inputs, processes them through OpenAI, and subsequently returns relevant feedback to the user interface.

3. Preliminary Results

The experimental procedure consisted of a pre-test (15 minutes), experiment activities (25 minutes), and a post-test (15 minutes). A total of 28 seventh-grade students who had not previously learned the target concept of this study participated in this study. This study initially investigated the impact of the AI tutor on junior high school students' learning outcomes in science experiments. Results indicated significant improvement, with average pre-test scores increasing from 2.35 (SD=1.68) to a post-test average of 7.32 (SD=4.94). A paired-sample t-test confirmed this significant gain (t = 5.67, p < .001), demonstrating effective learning outcomes. Behavioral observations revealed that the AI tutor effectively supported students in conducting experiments and enhancing conceptual understanding. In the observed cases, students moved the light source positions guided by the AI tutor and engaged in detailed observation of the ray paths. Before completing tasks, students repeatedly verified their understanding by visually aligning physical optical equipment, virtual ray paths, and the provided worksheets, ultimately leading to successful worksheet completion or ray-path drawings. These observations clearly illustrate enhanced student reflection and conceptual connections, confirming the AI tutor's efficacy in supporting students' understanding of optical refraction phenomena.

4. Conclusions and Challenges

The preliminary results indicate that the developed environment effectively supports students' construction of scientific concepts and fosters reflective observations, primarily due to the guidance provided by the AI tutor. However, the interaction analysis showed that students rarely initiated questions to the AI tutor, making it challenging for the AI to accurately assess students' understanding. Future research should consider implementing collaborative learning strategies or adjusting the AI interaction model to enhance student engagement and further improve interaction quality and learning outcomes.

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References

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Prentice-Hall.

Hofstein, A., & Kind, P. M. (2011). Learning in and from science laboratories. *Second international handbook of science education*, 189-207. https://doi.org/10.1007/978-1-4020-9041-7_15

Radu, I., & Schneider, B. (2023). How augmented reality (AR) can help and hinder collaborative learning: a study of AR in electromagnetism education. *IEEE transactions on visualization and computer graphics*, *29*(9), 3734-3745. https://doi.org/10.1109/TVCG.2022.3169980

George, D., & Mallery, P. (2016). *IBM SPSS Statistics 23 Step by Step: A simple guide and reference* (14th ed.). Routledge.

Gire, E., Carmichael, A., Chini, J. J., Rouinfar, A., Rebello, S., Smith, G., et al. (2010). The effects of physical and virtual manipulatives on students' conceptual learning about pulleys. In K. Gomez, L. Lyons, & J. Radinsky (Eds.), *Learning in the disciplines: Proceedings of the 9th international conference of the learning sciences* (ICLS 2010) (Vol. 1, pp. 937–944). Chicago: International Society of the Learning Sciences.

Gunturu, A., Jadon, S., Zhang, N., Faraji, M., Thundathil, J., Ahmad, T., ... & Suzuki, R. (2024). RealitySummary: Exploring On-Demand Mixed Reality Text Summarization and Question Answering using Large Language Models. *arXiv preprint arXiv:2405.18620*. https://doi.org/10.48550/arXiv.2405.18620