Majumdar, R. et al. (Eds.) (2025). Proceedings of the 1st International Conference on Learning Evidence and Analytics. Asia-Pacific Society for Computers in Education

A Game-Based Virtual Reality Context with Cognitive Prompts to Support Students' Problem-Solving and Cognitive Load Management

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Abstract: Inquiry-based learning supports knowledge construction but is challenging to implement in science classrooms. Virtual reality (VR) can visualize abstract concepts, and game-based learning promotes cognitive development and higher-order thinking. Reflection prompts help students link prior knowledge to new concepts. This study explored the effects of a game-based VR environment with embedded cognitive prompts on students' problem-solving and cognitive load. Using a one-group quasi-experimental design in an elementary school, students engaged in a science inquiry task via an interactive VR system with real-time prompts. Results showed improved problem-solving and significantly reduced cognitive load, supporting the effectiveness of cognitive prompts in enhancing learning and reducing mental demands in elementary science education.
Keywords: game-based learning, virtual reality, cognitive prompts, inquiry-based learning

1. Introduction

Inquiry-based learning (IBL) engages students in questioning, investigating, reflecting, and generating evidence-based solutions. IBL offers meaningful contexts for learning and knowledge construction, though its implementation in science education faces challenges. Inquiry learning is a complex process often conceptualized as a cycle of interconnected phases (Chen et al., 2023).

Virtual reality (VR) can visualize abstract concepts and support knowledge transfer through situated learning (Matovu et al., 2023). VR enables knowledge and skill transfer through situated learning. Effective VR integration requires specific instructional materials and careful consideration of its impact on learners (Krassmann et al., 2024).

Digital game-based learning fosters cognitive development and higher-order thinking through meaningful contexts. Contextual learning links cognition to real-life experiences, encouraging active learning (Panjaburee et al., 2025). Meaningful learning relies on both student engagement and sufficient cognitive processing. However, individuals have limited cognitive processing abilities. Well-designed multimedia can reduce cognitive load, while reflection prompts help integrate prior knowledge, deepen thinking, and enhance performance (Hung et al., 2014).

Thus, this study integrated the advantages of virtual reality, digital games, and cognitive prompts into inquiry-based science learning and conducted an empirical investigation in an elementary school. The research focuses on the following questions:

(1) Can a game-based virtual reality context with cognitive prompts enhance students' problem-solving tendencies?
(2) What levels of cognitive load do students experience during the learning process within a game-based virtual reality context with cognitive prompts?

2. Development of the virtual reality inquiry-based game

The VR game was developed with Unity 3D and Blender to create interactive scenes and objects. The game, themed “Preventing Rust and Preserving Food,” is designed for upper elementary students and aligns with inquiry-based learning principles. Students follow a narrative to help the protagonist solve mold contamination issues in a lab by completing tasks, collecting clues, and earning points. A task panel supports progress tracking, while interactions with NPCs and supplementary readings deepen their understanding.

3. Method

3.1 Participants

In this study, the participants were 28 fifth-grade students from an elementary school in Taipei City. A one-group quasi-experimental design was adopted to assess the differences in students’ problem-solving tendencies before and after learning through a game-based virtual reality approach and their perceived cognitive load during the learning process.

3.2 Experimental procedure

The learning procedure followed three sequential steps. First, students completed the pre-questionnaire on problem-solving before the learning activity. Next, they participated in a science inquiry learning activity with a game-based virtual reality system. Finally, they completed the post-questionnaire on problem-solving and a cognitive load questionnaire.

3.3 Measuring instruments

This study used problem-solving and cognitive load questionnaires. The problem-solving questionnaire, adapted from Hwang and Chen (2017), included pretest and posttest versions with five items on a five-point Likert scale (Cronbach’s $\alpha = 0.78$).

The cognitive load questionnaire, adapted from Hwang et al. (2013), includes two dimensions: mental load (5 items, Cronbach’s $\alpha = 0.86$) assessing intrinsic load during learning, and mental effort (3 items, Cronbach’s $\alpha = 0.85$) assessing extraneous load throughout the process.

4. Experimental result

4.1 Students’ problem-solving

A paired-sample t-test was conducted to examine the differences in students’ problem-solving tendencies before and after the learning activity. The results revealed a significant promotion in students’ problem-solving scores from pretest ($M = 3.70$, $SD = 0.92$) to posttest ($M = 4.09$, $SD = 0.67$) with $t = 2.19$ ($p < .05$). This indicates that the game-based virtual reality learning activity had a positive effect on enhancing students’ problem-solving tendencies.

4.2 Students’ cognitive load

A one-sample t-test revealed that students’ perceived cognitive load was significantly below the average level of 3. Specifically, the mean score for intrinsic cognitive load was 2.23 ($SD = 1.12$), which was significantly lower than 3 with $t = 3.64$ ($p < .01$). Similarly, the mean score for extraneous cognitive load was also 2.23 ($SD = 1.06$), significantly below the reference value with $t = 3.86$ ($p < .01$). The results showed that the game-based VR system imposed low cognitive load in both content and interface design.

5. Discussion and conclusions

This study showed that cognitive prompts in game-based VR effectively enhanced students' problem-solving and reduced cognitive load. The significant promotion in students' posttest scores indicates that the learning environment provided appropriate scaffolding to support learners in completing complex tasks, supporting them to apply and practice problem-solving strategies with greater clarity and focus. It is asserted that situated learning can assist students in connecting their cognitive structures with real-life experiences (Panjaburee et al., 2025). This study further confirmed that a game-based virtual reality context with cognitive prompts can foster students' problem-solving tendencies.

Furthermore, students reported significantly lower intrinsic and extraneous cognitive load, suggesting that cognitive prompts and system design helped manage content complexity and reduce unnecessary processing. This result echoes prior research indicating that well-designed reflection prompts deepen thinking and improve learning and problem-solving (Hung et al., 2014). These results show that cognitive prompts both direct attention and structure learning efficiently, making game-based VR a promising way to balance cognitive demands and support in elementary science education.

Acknowledgements

This study is supported in part by the National Science and Technology Council of Taiwan under contract numbers NSTC 112-2410-H-142-019 and NSTC 113-2410-H-142-005.

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