

Investigation on Learning Enhancement through AI-empowered Immersive Environment

Ping GENG¹

¹ Department of Food Science and Nutrition, The Hong Kong Polytechnic University, Hong Kong, China

Abstract

Traditional lecture-based education exhibits well-documented limitations, including relatively short knowledge retention times, low student engagement, and limited personalisation. This study presents a supplementary approach that enhances knowledge retention through engaging and immersive experiences. Piloted in the Department of Food Science and Nutrition, a metaverse platform integrating AI-driven virtual agents was developed to enhance students' understanding and motivation. Through surveys and focus group interviews with two cohorts of Year-3 students (N = 92) and analysis of 171 AI avatar responses in a representative food production scene, we find that students value the platform's interactivity, hands-on engagement, and novelty, reporting improved comprehension and enthusiasm over traditional methods. Thematic analysis highlights the AI avatars' supportive and explanatory communication style, which contrasts with students' short and fragmented inputs. Results also indicate students' preference for different immersion levels and provide valuable insights for the development of more engaging, personalised, and effective learning environments in higher education.

Keywords: AI agents, Immersive learning, Personalised learning pathway

1. Introduction

In the learning of science and engineering-related subjects, several challenges exist that need to be addressed. First, most subjects are lecture-based and exam-oriented, resulting in low knowledge retention after exams (Maceiras et al., 2025). Second, students crave more interactive and individualised approaches to learning (Walkington, 2013). Third, traditional learning materials may not sufficiently explain key concepts in vivid and interesting ways. For example, in the food technology domain, it is difficult for students to understand industrial food processing practices using only flowcharts, pictures, or videos. An immersive learning experience would be much more helpful for their knowledge construction process when the students behave as food engineers in food manufacturing factories (Gorman et al., 2022).

To address these challenges and help students achieve a higher level of learning beyond simple “remembering and understanding”, this project aims to create a unique, engaging, interactive, and immersive metaverse learning environment through a VR-based metaverse empowered by AI. The metaverse design is grounded in the theoretical foundations of: (1) gaming elements in immersive learning to encourage problem-solving (Mochizuki et al., 2021); (2) narratives in stories to promote sustained attention and deeper cognitive engagement (Dahlstrom, 2014); and (3) AI-powered virtual agents to simulate complex human interactions and provide timely and customised feedback (Zhou et al., 2020).

This study investigates three key research questions:

1. Can immersive technologies like the metaverse significantly enhance students’ learning engagement compared with traditional educational methods?
2. How do students interact with AI in an immersive environment?
3. How do students’ acceptance levels differ between VR and desktop/mobile devices for the exploration of a metaverse environment, given their different levels of immersion?

Through exploring these questions with empirical evidence, we can gain a deeper understanding of students’ perceptions in immersive, AI-powered learning environments and optimise platform design to enhance students’ learning experience. The findings from this study could provide insights for the development of more engaging, personalised, and effective educational platforms for a wide range of science and engineering disciplines.

2. Methodology

2.1 Participants

Participants (N = 92) in this study comprised two cohorts (23/24 and 24/25) of Year-3 students in the Department of Food Science and Nutrition taking the subject *Food Engineering and Processing II*. The gender distribution was balanced overall (48 Female / 44 Male), with an age range of 18–25 years.

2.2 Platform Design

This study has developed two metaverse scenes (a corn starch manufacturing plant and a beer brewery plant), each featuring different food production processes with over 100 smart non-player characters (NPCs). Students interacted with NPCs in the metaverse platform by tapping interactable icons on desktop computers or VR controllers (Figure 1a–d), which triggered dialogues and allowed for decision-making. The NPCs’ responses and guidance were dy-

namically tailored to the students' choices and actions, leading them through a sequence of approximately 30 tasks within each scene, enabling a personalised learning experience. A representative scene design is shown in Figure 1e–f.

Meanwhile, AI-powered avatars were integrated into the metaverse scenes, allowing students to interact with the avatars using text or voice and receive answers to any inquiries during their exploration (Figure 1h–i). The design of these GPT avatars utilises proprietary prompt templates to ensure that avatars delivered content relevant to the learning objectives. Instructors could easily modify the questions or define the AI avatars through the authoring tool in the platform (Figure 1g).

2.3 Implementation

During the implementation, students experienced both scenes: one with VR headsets (Meta Quest 3) and the other with less immersive desktop computers, for around 40 minutes respectively. After experiencing two metaverse scenes in two different modes, students were invited to complete a semi-structured survey designed to evaluate their user experience and acceptance of the metaverse platform. The survey incorporated both 5-point Likert scale questions and open-ended questions based on the modified Technology Acceptance Model (TAM) for immersive design (Fussell & Truong, 2022). A focus group interview was also conducted with 20 randomly selected participants.

2.4 Data Analysis

Descriptive analysis and T-tests were employed to identify distribution differences in the constructs of TAM and preference in different immersion levels (VR and desktop computers). Meanwhile, thematic analysis informed by word frequency counts was used to analyse students' feedback in focus group interviews and identify key concepts and patterns in the AI avatar's replies.

3. Results and Discussion

3.1 Qualitative Feedback on the Platform's Strengths and Weaknesses

The qualitative results came from both the open-ended qualitative responses in the survey and subsequent focus group interviews through thematic analysis. The representative positive feedback could be divided into the following three categories:

(1) Interactivity and hands-on engagement: Students appreciated the active, task-based nature of the immersive learning environment. They enjoyed opportunities to physically interact with content rather than passively absorbing information. Representative comments include:

- “Fun and more interactive.”
- “I like interactive tasks, like grabs and selection, better than MCQ and text. I think it can have more interactive tasks and animations.”

(2) Enhanced learning and comprehension: The participants noted that the immersive learning experience enhanced their understanding of information compared to traditional methods. The ability to visualise and handle simulated equipment was highlighted as a key benefit. Representative comments include:

- “Memorising the information was easier because you see the actual equipment.”
- “I like the grabs and while I was doing it I felt I was really there. It’s better than reading the text and it helps me to learn the process.”
- “VR simulation... helped me to see the whole process that I can’t see in real life and it enhances my learning.”

(3) Novelty and engagement in the learning experience: Many student participants expressed enthusiasm for the fresh, innovative approach of the AI-empowered metaverse platform. Representative comments include:

- “I think it’s really fresh and I prefer VR to the traditional way.”
- “Walking in a factory doing this thing and that thing... it’s interesting and better than reading the text.”

Meanwhile, we also received students’ feedback indicating challenges for further improvement. The weaknesses mainly involve dizziness issues and technical difficulties when using VR headsets, as well as relatively slow response times and fast speaking speeds of AI avatars.

3.2 Gen-AI Usage in the Metaverse Platform

We analysed 171 replies generated by the Gen-AI avatar in the scene of the beer brewery plant after cleaning (lowercasing, removing punctuation, URLs, and stop words). It was discovered that on the avatar side, all 171 replies were analyzable and were substantially longer (median 12 content words, $M = 12.85$). The vocabulary was strongly dominated by explanatory brewing language (*fermentation, process, purpose, mashing, primary, secondary, convert, sugar, enzyme, alcohol*), reflected enthusiastic introductions (“Great! Let’s dive into...”), and supportive context management (“I understand you’re stepping away...”).

Through comparing the input from students and replies from Gen-AI, results show that students bring short, sometimes fragmented or emotional input (“What is the difference between ...”, “Uh primary fermentation is ..., right”,

“Pretty good”), whereas the Gen-AI avatar responds with longer, more uniformly structured, and generally positive explanations. The replies not only mirror the brewing content but also add layers of encouragement, clarification, and repair, especially when students appear confused or frustrated.

3.3 Comparison Between Different Immersion Modes

The evaluation survey was developed on the basis of the modified Technology Acceptance Model (TAM) (Fussell & Truong, 2022) to identify students’ preference on different immersion levels (VR and desktop computers). Key aspects include the functionality of interactive elements and user interface (TECH), attitudes towards learning in the metaverse (ATT), ease of use (EASE), enjoyment (ENJ), perceived productivity (PERF), perceived usefulness (USE), intent to use (INT), and usage behaviour (BEH).

As shown in Table 1, notable device-based differences could be observed. Desktop users reported significantly higher ratings across multiple constructs, including behavioural intention (BEH) (4.023 vs. 3.375) and perceived usefulness (USE) (4.227 vs. 3.438), highlighting a preference for desktop interactions. Additionally, ease of use (EASE) was rated higher for desktop users (4.182) compared to VR headset users (3.500), indicating that desktop-based interactions were perceived as more intuitive and accessible. T-test results further exhibit the significant differences, with desktop users reporting higher usage behaviour (BEH) ($p = 0.027$), enjoyment (ENJ) ($p = 0.014$), ease of use (EASE) ($p = 0.014$), and perceived usefulness (USE) ($p = 0.008$) than VR headset users. The comparison suggests that students using desktop computers experience greater independence and enjoyment on the metaverse platform, feel more confident in using it, and perceive it as more useful compared to those using VR headsets.

4. Implications

The application of an interactive metaverse with AI-empowered avatars offers a promising enhancement to traditional lecture-based teaching, providing students with an engaging and enjoyable learning experience that reinforces their knowledge. Positive student feedback, along with the increase in eSFQ scores from 4.3 in 2022/23 to 4.6 in 2023/24 and 4.7 in 2024/25, suggests that this approach can be further leveraged to maximise its benefits, particularly in supporting knowledge construction through ongoing reinforcement.

Here are some recommendations based on the findings from this study:

- While the current design incorporates multiple knowledge delivery methods (MCQs, videos, drag-and-drop interactions), students ex-

pressed a preference for interactive tasks. Therefore, future metaverse design should prioritise user-friendly interactive elements to enhance learning effectiveness (Ali, 2025).

- Statistical analysis revealed that desktop users reported significantly higher behavioural intention, enjoyment, and ease of use compared with VR users. Although students acknowledged VR's novelty, discomfort and dizziness remained concerns (Rebenitsch & Owen, 2016). A desktop or mobile version of the metaverse could offer greater accessibility, reduce motion sickness, allow flipped learning before class, and self-tutoring after class.
- In addition, AI avatars increase the interactivity of the metaverse platform. Due to students' varied requirements for AI avatars, efforts could be made to further customise the styles of AI avatars based on students' individual needs, creating a more personalised learning experience (Kim & Baylor, 2016).

Acknowledgments

This work was supported by PolyU Teaching Development Grant (Grant No. 49SZ) and Fund for Innovative Technology-in-Education-Inter-Institutional Collaborative Activities (FITE-IICA) (Grant No. 89VR). The authors gratefully acknowledge the financial support provided by both projects.

Ethical Declaration Statement

The project has been approved by the Institutional Review Board of The Hong Kong Polytechnic University (Reference Number: HSEARS20230808006).

Declaration of Use of AI in the Writing Process

The author(s) used PolyU GenAI during the preparation of this work to assist with grammar polishing. After utilising the tool, the author thoroughly reviewed and edited the content as necessary and assumed full responsibility for the publication's content.

References

- Ali, M. (2025). Fostering Engagement and Motivation: Evaluating Gamified Learning in the Metaverse for Architectural History Education. *International Journal of Interactive Mobile Technologies*, 19(6). <https://doi.org/10.3991/ijim.v19i06.53841>
- Dahlstrom, M. F. (2014). Using narratives and storytelling to communicate science with nonexpert audiences. *Proceedings of the National Academy*

- of Sciences, 111(supplement_4), 13614–13620. <https://doi.org/10.1073/pnas.1320645111>
- Fussell, S. G., & Truong, D. (2023). Accepting virtual reality for dynamic learning: An extension of the technology acceptance model. *Interactive Learning Environments*, 31(9), 5442–5459. <https://doi.org/10.1080/10494820.2021.2009880>
- Gorman, D., Hoermann, S., Lindeman, R. W., & Shahri, B. (2022). Using virtual reality to enhance food technology education. *International Journal of Technology and Design Education*, 32(3), 1659–1677. <https://doi.org/10.1007/s10798-021-09669-3>
- Kim, Y., & Baylor, A. L. (2016). Research-Based Design of Pedagogical Agent Roles: a Review, Progress, and Recommendations. *International Journal of Artificial Intelligence in Education*, 26, 160–169. <https://doi.org/10.1007/s40593-015-0055-y>
- Maceiras, R., Feijoo, J., Alfonsin, V., & Perez-Rial, L. (2025). Effectiveness of active learning techniques in knowledge retention among engineering students. *Education for Chemical Engineers*, 51, 1–8. <https://doi.org/10.1016/j.ece.2025.01.003>
- Mochizuki, J., Magnuszewski, P., Pajak, M., Krolikowska, K., Jarzabek, L., & Kulakowska, M. (2021). Simulation games as a catalyst for social learning: The case of the water-food-energy nexus game. *Global Environmental Change*, 66, 102204. <https://doi.org/10.1016/j.gloenvcha.2020.102204>
- Rebenitsch, L., & Owen, C. (2016). Review on cybersickness in applications and visual displays. *Virtual Reality*, 20, 101–125. <https://doi.org/10.1007/s10055-016-0285-9>
- Walkington, C. A. (2013). Using adaptive learning technologies to personalize instruction to student interests: The impact of relevant contexts on performance and learning outcomes. *Journal of Educational Psychology*, 105(4), 932. <https://doi.org/10.1037/a0031882>
- Zhou, L., Gao, J., Li, D., & Shum, H. Y. (2020). The design and implementation of xiaoice, an empathetic social chatbot. *Computational Linguistics*, 46(1), 53–93. https://doi.org/10.1162/coli_a_00368

Table 1: Descriptive ratings and T-test result of VR and desktop/mobile modes of metaverse learning environments

Constructs	Desktop/mobile devices		VR headsets		p
	Mean	SD	Mean	SD	
BEH	4.023	0.794	3.375	1.182	0.027
ENJ	4.136	1.049	3.438	1.116	0.014
ATT	4.250	0.856	3.604	1.170	0.030
INT	4.136	0.743	3.417	1.204	0.019
EASE	4.182	0.839	3.500	1.063	0.014
USE	4.227	0.736	3.438	1.126	0.008
TECH	3.886	0.912	3.563	1.097	0.177
PERF	4.114	0.925	3.438	1.155	0.019

Note: N = 92. Participants were on average 21 years old with 52% female participants. Abbreviations: BEH: usage behaviour; ENJ: enjoyment; ATT: attitudes towards learning in the metaverse; INT: intent to use; EASE: ease of use; USE: perceived usefulness; TECH: interactive elements and user interface; PERF: perceived productivity.

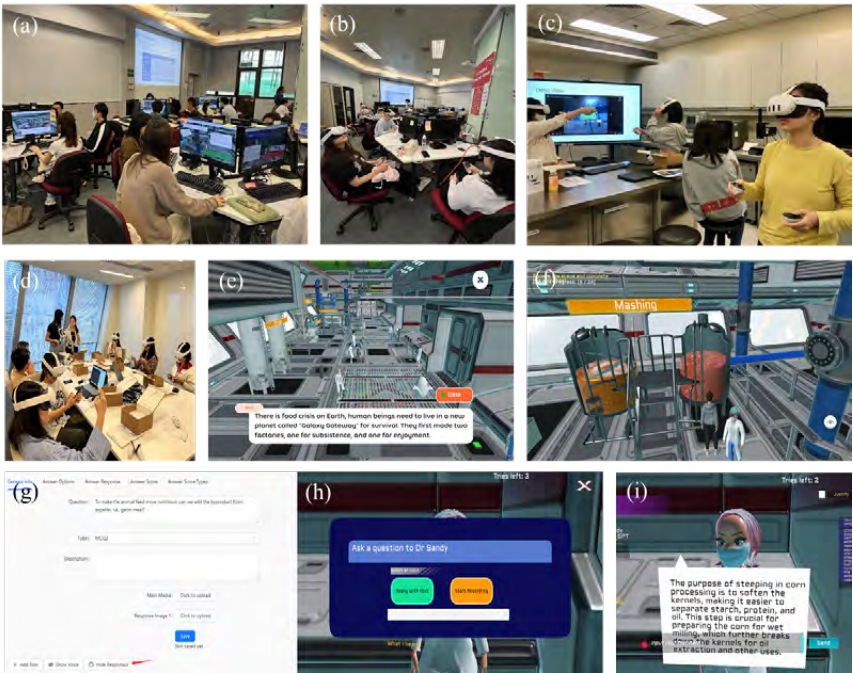


Figure 1: AI-powered metaverse environment.

(a)–(d) Implementation of metaverse platform for immersive learning.

(e)–(f) Part of the immersive learning environment design for food science education.

(g) Authoring tool interface allowing the modification of questions by instructors.

(h)–(i) AI-powered avatars in the metaverse scene for personalised learning.