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Marrying Physical and Virtual Realms: An Embodied, Multi-Modal Approach to Situational Learning in Digital Reality

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Abstract: In the realm of digital education, traditional virtual reality setups often confine students to basic interactions through devices like a mouse and handheld controllers, limiting immersive learning opportunities, particularly in disciplines requiring multi-modal knowledge such as hospitality and teacher training. Multi-modal knowledge encompasses physical actions, gestures, facial expressions, and other non-verbal communication. This study investigates a novel educational approach that synchronizes physical settings with digital reality scenarios, aided by AI Stereo Cameras (e.g., Apple Vision Pro or MetaQuest), to create a more interactive learning experience. A three-group quasi-experimental design involved 103 Taiwanese students practicing hospitality tasks, such as table service in a simulated Japanese restaurant. The groups included: Group A, handling physical utensils in a real-world-like setting; Group B, controlling virtual utensils with a mouse; and a control group, learning through conventional teaching. Findings reveal that Group A reported significantly better learning outcomes and reduced cognitive load compared to Groups B and C. The reduced cognitive load was attributed to the use of real physical utensils, which minimized the need for students to learn how to navigate virtual utensils using a mouse. The findings underscore the benefits of incorporating physical objects into VR environments, bridging the gap between traditional and digital educational modalities. This approach offers a practical framework for situated learning in educational settings, incorporating embodied and multi-modal learning, and suggesting its broad applicability in improving educational practices and outcomes in the digital age.

Keywords: Digital Reality, Virtual Reality, Embodied Cognition, Multi-Modal Knowledge, Situational Learning, Cognitive Load

1. Introduction

In the evolving landscape of educational technology, digital reality (DR) has emerged as a pivotal tool in transforming the learning experience, enabling immersive and interactive scenarios that transcend traditional classroom boundaries. Virtual Reality (VR), a cornerstone of DR, allows students to navigate and interact within constructed digital contexts, offering novel avenues for engagement and understanding (Berkman & Akan, 2024). However, the current utilization of VR in education, predominantly reliant on mouse and handheld device interactions, presents limitations in courses demanding the acquisition of multi-modal knowledge—such as facial expressions, posture, gestures, and other non-verbal cues integral to fields like hospitality and teacher training (Bailenson et al., 2018; Islam & Kirillova, 2021).

Recognizing these constraints, this study introduces an innovative approach that bridges the gap between digital immersion and physical experience. We propose the integration of physical settings that correspond to the digital scenarios encountered in VR, facilitating a comprehensive learning experience that encompasses both sensorimotor and cognitive aspects of learning. This methodology is particularly pertinent in disciplines requiring nuanced interpersonal interactions and physical presence, exemplified by a scenario where Taiwanese students learn to serve in a Japanese restaurant—a setting that demands mastery over a suite of multi-modal skills beyond mere textual and linguistic proficiency.

The need for such an integrative approach is underscored by the embodied cognition theory, which posits that cognitive processes are deeply rooted in the body's interactions with the world (Fugate, Macrine, & Cipriano, 2019; Wilson, 2002). Embodied learning, as advocated by Lindgren and Johnson-Glenberg (2013), emphasizes the role of physical movement and sensory feedback in enhancing cognitive outcomes, suggesting that learning environments should engage the learner's entire sensorimotor system to maximize educational effectiveness. Furthermore, situational learning theory (Lave & Wenger, 1991) highlights the importance of context and practice in the social process of learning. By situating students in authentic or highly realistic environments, they are better prepared for real-world applications of their skills and knowledge (Al Hakim, Yang, Liyanawatta, Wang, & Chen, 2022). Our approach extends situational learning into the realm of digital reality, allowing for a seamless integration of authentic practice and digital exploration.

Therefore, we propose a novel educational framework that synergizes the immersive potential of digital reality with the tangible, sensorimotor engagement of corresponding physical environments. This dual-modality learning model not only adheres to the principles of embodied cognition and situational learning but also leverages technology to create a rich, multi-modal learning experience that is both engaging and educationally potent. By reducing the abstract manipulation of virtual interfaces, we aim to lower cognitive load, making the learning process more intuitive and less mentally taxing. This approach not only addresses the limitations of current DR applications in multi-modal knowledge acquisition but also sets a new benchmark for immersive, embodied learning experiences. This study is guided by two research questions:

1. Do students who learn by manipulating physical utensils in a real-world replicated setting show better learning achievements than those learning with virtual utensils using a mouse or through conventional classroom teaching?
2. Do students who learn by manipulating physical utensils in a real-world replicated setting show lower cognitive load than those learning with virtual utensils using a mouse or through conventional classroom teaching?

2. Theoretical Framework

This study integrates several key theoretical perspectives to inform its approach to enhancing educational experiences through the combination of physical and virtual environments. The theories provide a robust framework for understanding and evaluating the potential benefits of our proposed educational model.

2.1 Digital Reality

Digital reality encompasses a spectrum of technologies, including virtual reality (VR), augmented reality (AR), and mixed reality (MR), that blend digital and physical elements to create immersive environments. These technologies have transformative potential in education by providing interactive and engaging learning experiences that go beyond traditional methods (Bailenson, 2018).

Jing et al. (2024) conducted a meta-analysis highlighting the effectiveness of VR-based instruction in improving learning outcomes across various educational levels. The immersive nature of VR allows for experiential learning, where students can engage in realistic simulations that enhance understanding and retention. Johnson-Glenberg et al. (2021) found that embodied VR experiences, which integrate physical movements with digital interactions, significantly improve cognitive and affective learning outcomes. Further, such environment can facilitate the development of multi-modal skills by allowing learners to practice and refine complex behaviors in a controlled, virtual environment. This is particularly beneficial for fields like hospitality service and teacher training, where mastering non-verbal cues such as facial expressions, posture, and gestures is crucial (Islam & Kirillova, 2021).

Our study deviates from traditional approaches by using real physical objects to control the virtual environment instead of VR controllers or a mouse. Aided by AI Stereo Cameras, this method allows students to manipulate physical utensils, such as forks and spoons, projected into the virtual world. This approach not only enhances the immersive experience but also addresses the limitations of current VR applications, such as the lack of tangible interactions and the potential for high cognitive load due to abstract interfaces. The synergy between digital and physical elements creates a comprehensive learning environment that is both engaging and educationally effective.

2.2 Embodied Cognition

Embodied cognition theory posits that cognitive processes are deeply rooted in the physical interactions of the body with its environment. Wilson (2002) argues that traditional cognitive theories, which often isolate mental processes from physical activities, fail to capture the holistic nature of human cognition. Embodied cognition suggests that physical movement and sensory experiences play a critical role in cognitive development and functioning. This theory is supported by research showing that learners who engage physically with their learning materials often achieve better understanding and retention (Barsalou, 2008; Shapiro, 2019).

Lindgren and Johnson-Glenberg (2013) extend this theory to educational contexts, proposing that learning environments should actively engage the sensorimotor system to enhance cognitive outcomes. Their research indicates that activities involving physical manipulation of objects can significantly improve students' comprehension and memory. This aligns with our approach of integrating physical settings with digital scenarios, aiming to leverage the benefits of embodied learning to create a more immersive and effective educational experience.

2.3 Multi-Modal Knowledge

Multi-modal knowledge refers to the integration of various forms of communication and interaction, including physical actions, gestures, facial expressions, and other non-verbal cues (Baig & Kavakli, 2020). This type of knowledge is particularly crucial in disciplines like hospitality and teacher training, where effective communication and interaction are essential (Islam & Kirillova, 2021). Research indicates that multi-modal learning environments, which engage multiple senses and forms of interaction, can significantly enhance understanding, retention, and application of knowledge (Gordani & Khajavi, 2020).

By incorporating multi-modal elements into our immersive learning approach, we aim to create a more holistic and effective learning experience. This allowing student to practice and refine their skills in a realistic yet controlled setting. This approach not only improves learning outcomes but also prepares students for real-world applications by providing them with the tools to master complex, multi-faceted tasks.

2.4 Situational Learning

Situational learning theory, developed by Lave and Wenger (1991), emphasizes the social and contextual aspects of learning. According to this theory, learning is a process of becoming part of a community of practice through participation in authentic activities. Brown, Collins, and Duguid (1989) further highlight that learning is most effective when it occurs in contexts that replicate real-world environments. This is because such environments provide learners with meaningful and relevant contexts that enhance their ability to transfer and apply knowledge and skills to real-world situations, fostering deeper understanding and retention (Al Hakim, Yang, Liyanawatta, Wang, & Chen, 2022).

This theory supports our approach of creating physical environments that mirror digital scenarios, providing students with authentic, practice-based learning opportunities. By situating learners in realistic settings, we aim to facilitate the transfer of skills and knowledge to real-world applications, thereby enhancing the relevance and impact of the educational experience.

2.5 Cognitive Load

Cognitive load theory, introduced by Sweller (1988), addresses the capacity limitations of working memory and emphasizes the need to design instructional materials that optimize cognitive resources. The theory distinguishes between intrinsic cognitive load (related to the inherent difficulty of the content), extraneous cognitive load (related to the way information is presented), and germane cognitive load (related to the processes that contribute to learning).

Sweller, Ayres, and Kalyuga (2011) argue that reducing extraneous cognitive load is crucial for enhancing learning efficiency. This can be achieved by designing learning activities that align with the learner’s cognitive capabilities and minimize unnecessary mental effort (Grund et al., 2024). By using physical utensils that are more intuitive and familiar to learners, our approach aims to reduce extraneous cognitive load compared to traditional VR interfaces, making the learning process more efficient and less mentally taxing.

2.6 Conclusion

In synthesizing these theoretical perspectives, our study proposes a novel educational framework that merges the immersive potential of digital reality with the tangible engagement of physical environments. By drawing on embodied cognition, multi-modal knowledge, situational learning, and cognitive load theories, we aim to create an educational model that enhances learning outcomes and reduces cognitive load. This integrated approach represents a significant advancement in the field of technology-enhanced learning, offering a new paradigm for the deployment of digital reality in education.

Figure 1. Design concept of the system.

3. System Design and Implementation

3.1 Design Concept

Our study provides new insights into using digital reality by moving beyond traditional VR controllers for controlling virtual objects. Instead, we utilize 3D cameras and AI to detect objects and movements, allowing students to practice with real physical objects like forks, spoons, and glasses, which are then projected into the virtual world (Figure 1 left). This innovative approach integrates physical operations into digital reality scenarios without the need for VR controllers or a mouse (Figure 1 right). Using easily programmable 3D cameras with YOLO for image recognition, multiple users and surrounding objects are simultaneously integrated into the digital reality. This method allows learners to engage in scenario-based learning from a third-person perspective, enabling them to observe their learning performance and engage in reflective learning. By simplifying key learning content into physical activities within a classroom setting, our approach creates a comprehensive and immersive learning environment that bridges the gap between traditional and digital educational modalities.

3.2 System Architecture

The proposed learning system designed in this study consists of four main components: The Cyber Physical Synchronization (CPS) system, the physical-virtual learning space, the script editor, and the script controller, as shown in Figure 2.

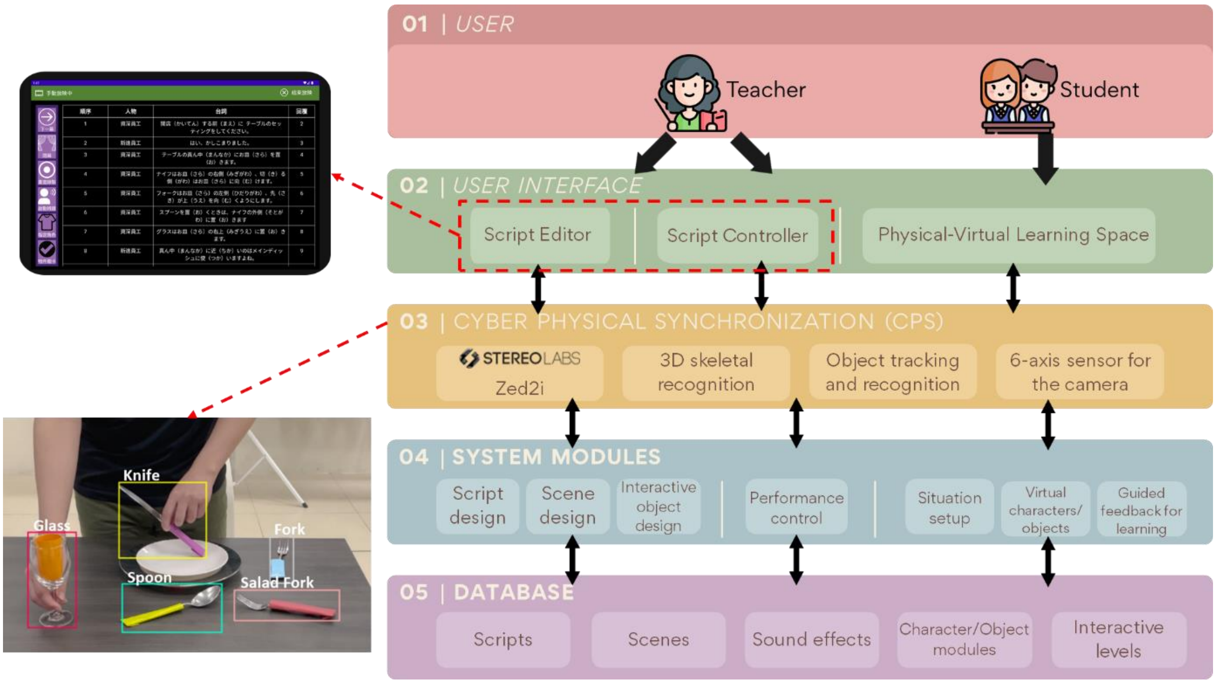

Figure 2. The system architecture.

- <u>Cyber Physical Synchronization (CPS) System</u>: As the core of the architecture, the CPS system is responsible for calculating and integrating synchronization methods, sending information to the physical-virtual learning space and script editor. It uses the Zed 2i – AI Stereo Camera to synchronize multiple modalities, such as users' expressions, postures, and gestures, as well as the movement and positions of objects on the physical-virtual learning space.
- <u>Physical-Virtual Learning Space</u>: Responsible for script playback and constructing 3D digital scenes, creating an immersive learning environment. It receives object and limb recognition results generated by the CPS system, producing 3D models and virtual avatars at corresponding locations. Additionally, the system provides spatial auxiliary information such as angles and distances on the screen, helping students establish a spatial sense that closely approximates the real world within the virtual environment. Essential hardware for this component includes projectors to display the virtual environment.
- <u>Script Editor</u>: Assists teachers in converting textbook content into situational teaching materials. Teachers can use an Android tablet to edit scripts, scenes, props, and other elements, making the learning materials more suitable for educational needs.

- Script Controller: Allows teachers to control the progression of the script performance, providing real-time feedback and assessment during the students' learning process.

The overall design aims to provide an interactive, multi-sensory learning environment where students can enhance their learning outcomes through physical interactions with the virtual environment.

4. Experimental Design

An experimental design was conducted to compare the effectiveness of three different learning environments: experimental group A (handling physical utensils in a setting that closely mimics real-world conditions), experimental group B (using virtual utensils with a mouse as the controller), and a control group (conventional classroom teaching), with the aim of evaluating their impact on both learning outcomes and cognitive load among students. The measurement tools included: (1) pre- and post-tests to measure learning outcomes, (2) questionnaires to assess cognitive load, and (3) interviews. Details are as follows:

4.1 Participants

This study was conducted in collaboration with a university in Taoyuan City. Participants were from three classes in a hospitality Japanese course. One class was randomly assigned to experimental group A, another to experimental group B, and the third to the control group. Excluding those who were absent or affected by the pandemic, experimental group A consisted of 35 students, experimental group B had 35 students, and the control group had 33 students. All groups were taught by the same teacher to ensure consistency in instructional delivery. All groups were completely independent and did not influence each other during the experiment. All participants provided informed consent and the study was conducted in accordance with ethical guidelines approved by the university's ethics committee.

4.2 Instructional materials

The instructional materials for this experiment were designed by the hospitality Japanese course instructor. The materials were based on the course syllabus and student proficiency levels, and were edited into a script for a restaurant scenario. The script combined Japanese vocabulary, grammar, and greetings learned in class with restaurant service knowledge and etiquette, such as table setting and serving order. Realistic scenarios included training new employees, taking orders, and processing payments, aiming to train students' Japanese communication expression and practical application skills.

4.3 Evaluation tools

To evaluate the impact of the proposed learning system on learners, this study used pre- and post-tests and related questionnaires. The evaluation of learning outcomes was conducted before and after the experiment, including pre-tests and post-tests, combined with questionnaires to deeply analyze learners' experiences after using the system.

The pre- and post-tests were designed by the hospitality Japanese course instructor and covered topics within the learning scope. Each included 15 fill-in-the-blank questions, and the scoring scale ranged from 0 to 100. The tests included basic Japanese for hospitality, table setting, and table service techniques. The test results were statistically analyzed using ANCOVA.

The questionnaire was designed using a Likert five-point scale, with scores ranging from 1 (strongly disagree) to 5 (strongly agree). The questionnaire assessed cognitive load dimension. The cognitive load items were based on Paas, Tuovinen, Tabbers & Van Gerven (2016), assessing the cognitive load required to use the learning system. One example question was: "The way material was taught make me work hard mentally during the learning activity." The Cronbach's α value was 0.85. The test results were analyzed statistically using ANOVA.

To further understand the experiences of students in experimental groups A and B with the physical-virtual learning space and to gather teachers' opinions about the learning-teaching process using the system, random interviews were conducted with both students and their teachers from these groups after the post-test.

4.4 Experimental procedure

The experiment lasted for eight weeks and was designed according to the learning model proposed in this study, as shown in Figure 3. All three groups followed the same procedure and instructional materials. The instructor taught basic Japanese knowledge and situational materials according to the weekly schedule. During the situational learning and presentation stages, students worked in groups to perform tasks, with grouping based on pre-test scores to ensure balanced abilities among groups.

During the intervention, students in Experimental Group A learned Japanese hospitality knowledge by manipulating physical utensils in a real-world replicated setting (Figure 4 left). Experimental Group B students learned using virtual utensils with mouse as controller (Figure 4 right). While students in Control Group learned through conventional classroom teaching methods without contextual virtual environment. Each group followed the same curriculum and participated in similar learning activities, ensuring consistency in the educational content delivered.

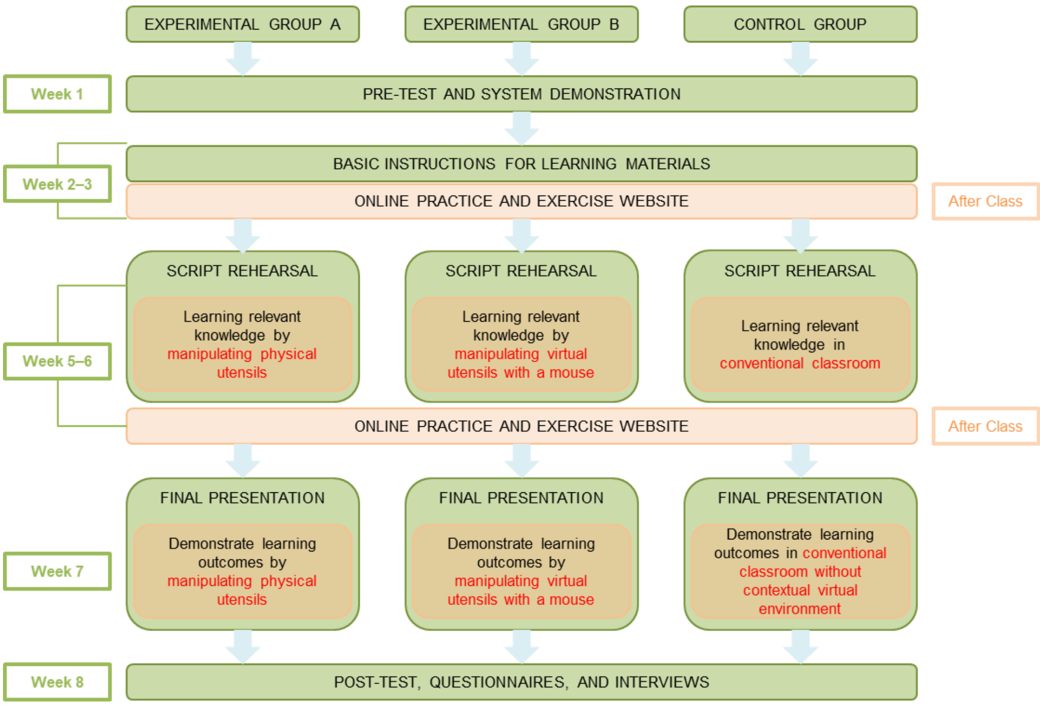

Figure 3. Experimental procedure.

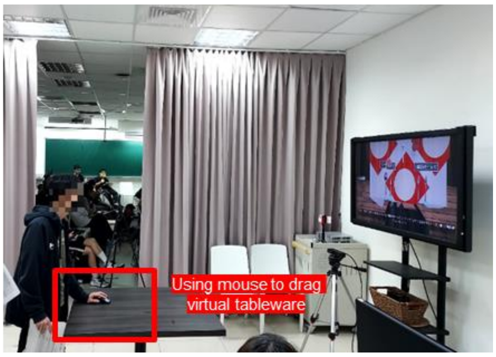

Figure 4. Experimental Group A and B interventions.

5. Findings and Discussion

The findings of this study reveal significant differences in learning outcomes and cognitive load among the three groups. The results highlight the advantages of integrating physical elements into digital learning environments, as well as the effectiveness of immersive technologies in enhancing educational experiences. Table 1 displays a summary of the experimental data.

Table 1. *Summary of the experimental data*

Measure	Group	*N*	Mean	SD	F-value	Pairwise Comparisons	Effect Sizes (η_p^2)
Learning outcomes	Exp. A	35	85.2	4.3	29.34*	A > B	0.367
	Exp. B	35	78.5	5.1		A > C	
	Control	33	72.8	6.0		B > C	
Cognitive load	Exp. A	35	2.3	0.4	22.18*	A < B	0.305
	Exp. B	35	3.5	0.5		A < C	
	Control	33	3.0	0.6		C < B	

*$p < 0.05$

5.1 Learning Outcomes

The ANCOVA of learning outcomes showed that Group A (handling physical utensils) achieved significantly higher scores compared to both Group B (using virtual utensils) and the control group (conventional classroom teaching). This result suggests that the integration of physical objects in a digital learning environment can enhance students' understanding and retention of course material.

The improved performance of Group A can be attributed to the embodied cognition theory, which posits that physical interaction with learning materials enhances cognitive processing and memory retention (Barsalou, 2008; Fugate, Macrine, & Cipriano, 2019). Moreover, it was also found that the Group B had significantly higher learning achievements than control group, implying that learning in a simulated learning environment has better effects on learning outcomes of students than the conventional ones. By manipulating objects in simulated environments, students were able to engage more deeply with the learning content, leading to better comprehension and application of knowledge.

5.2 Cognitive Load

The analysis of cognitive load showed that students in Group A experienced significantly lower cognitive load compared to those in Group B and the control group. This reduced cognitive load can be attributed to the absence of additional learning required for virtual utensil use. Moreover, the pairwise comparison results revealed that the control group had significantly lower cognitive load than Group B, implying that learning with a real utensil has better effects on cognitive load of students than the virtual ones.

Sweller's cognitive load theory suggests that reducing extraneous cognitive load allows for more efficient use of cognitive resources, thereby enhancing learning (Grund et al., 2024; Sweller et al., 2011). In this study, the use of familiar physical utensils in Group A and control group minimized extraneous cognitive load, allowing students to focus more on learning the content rather than navigating the interface.

5.3 Interview results

5.3.1 Student interviews

Students in Group A expressed that manipulating physical utensils made the learning process more engaging and intuitive. One participant noted, "Using the actual utensils made the learning experience feel real. I was more motivated to participate and practice." Another added, "Practicing with real utensils helped me understand the tasks better. I feel more confident in performing these tasks in real life." In contrast, students in Group B found the VR environment engaging initially but faced challenges due to the lack of tactile feedback and the complexity of using a mouse. One student mentioned, "The VR setup was interesting at first, but after a while, it became harder to use the virtual utensils compared to real ones." Another stated, "Learning to use the mouse took some time. It added an extra layer of difficulty to the tasks."

5.3.2 Teacher interviews

Teachers observed that students in Group A were more engaged and performed tasks with greater confidence and accuracy. One teacher commented, "The physical utensils allowed students to practice realistically, which significantly improved their skill application." Another noted, "Students seemed more focused and less frustrated when using physical tools compared to virtual ones." However, teachers also recognized the potential of VR environments for visualizing complex scenarios, with one stating, "While the VR tools had a learning curve, they provided a unique way for students to visualize tasks that are hard to replicate physically."

These interview results support the quantitative findings, showing that Group A experienced lower cognitive load, which contributed to better learning outcomes. Group B, despite the immersive benefits of VR, struggled with usability issues that impacted their learning effectiveness. Teacher feedback highlighted the importance of balancing physical and digital elements to maximize learning benefits. These insights emphasize the need for further refinement of VR tools to better support practical skill development and the integration of both modalities to enhance overall learning experiences.

6. Conclusion, Limitations, and Future Works

6.1 Conclusion

This study demonstrates that integrating physical elements into virtual learning environments significantly enhances learning outcomes and reduces cognitive load. Students using physical utensils in a physical-virtual learning space performed better and felt more confident than those using virtual utensils with a mouse, or those in conventional classrooms. These findings support embodied cognition and situational learning theories, emphasizing the importance of physical interaction in education.

6.2 Limitations and Future Works

This study has several limitations. The sample size was small and limited to hospitality Japanese courses, which may affect the generalizability of the results. The eight-week duration may not capture long-term effects, and reliance on self-reported measures for cognitive load introduces potential bias.

Future research should explore physical-virtual learning spaces in various educational contexts and disciplines to validate these findings. Long-term studies are needed to assess the sustained impact. Integrating advanced technologies like personalized feedback mechanism (Panjaburee et al., 2024) and augmented reality (Bressler & Tutwiler, 2021; Drljević, Botički & Wong, 2024) could further enhance learning and engagement. Additionally, optimizing the design and implementation of physical-virtual learning environments, developing guidelines for educators, and exploring cost-effectiveness and scalability—such as digital twin technology—are crucial for broader adoption. Incorporating gamification elements could also be explored due to their potential to increase enjoyment in learning activities (Zeng, Sun, Looi & Fan, 2024). Collaborative studies across multiple institutions and disciplines can provide a comprehensive perspective on the efficacy of physical-virtual learning spaces.

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