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Guiding the Redesign of a VR-based Photolithography Training from Domain Experts' Perspective: A Think-Aloud Study

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Abstract. This academic full paper presents the use of think-aloud protocol for collecting real-time user insights on an immersive VR-based photolithography training from domain experts. Findings reveal that usability challenges extend beyond basic interaction issues and are largely rooted in instructional design. Based on these insights, the study proposes a set of actionable design considerations, organized into meta, pragmatic, and specific levels, to guide future system iterations. The results highlight the importance of iterative, feedback-driven design processes that integrate usability and pedagogical evaluation to ensure VR training tools are both technically functional and instructionally effective.

Keywords: Virtual Reality, Engineering Education, Photolithography Training, Think-Aloud Protocol, Design Considerations.

1 Introduction

Virtual reality (VR) has introduced new possibilities in education and training, enabling safe, controlled simulations of complex or hazardous environments [1]. Previous researchers have applied VR technology in various settings, such as military training, healthcare, safety, and engineering training [2–5]. As a rapidly evolving technology, VR holds the potential to revolutionize the way we approach technical education, particularly in fields requiring high levels of precision and safety, such as semiconductor fabrication [6]. In semiconductor fabrication, photolithography process is essential yet difficult to master, requiring extensive hands-on practice. Traditional training through cleanrooms poses challenges due to high costs, strict safety protocols, and limited access [7], restricting students' opportunities for repeated practice. To address this, engineering educators are turning to VR as an alternative, offering realistic, interactive simulations that overcome these barriers.

While research on VR usability in educational contexts is growing, many evaluations rely primarily on post-session measures such as questionnaires or interviews, which risk missing real-time insights into learner-system interaction [8]. The Think-Aloud Protocol (TAP) offers a complementary approach by capturing users' cognitive processes and immediate reactions as they engage with tasks [9, 10]. Typically, TAP is oftentimes conducted with end-users [11]. While this approach is valuable for understanding user experience with fresh eyes, novice learners often lack sufficient subject-matter knowledge, which may limit the depth of their feedback for informing domain-specific learning design. To ensure that a VR learning experience accurately mirrors curricular objectives and authentic training requirements, the involvement of domain experts (also known as subject experts) is critical [12]. Expert's feedback serves a dual purposes: they validate the alignment between VR prototypes and real-world instructional practices, also provide specific feedback necessary to improve the instructional precision, particularly in specialized domains such as semiconductor fabrication [13, 14]. More importantly, involving domain experts into the iterative system design and development process is often regarded as a common and effective approach for early-stage prototyping [15]. Despite some preliminary studies introducing VR engineering lab trainings, systematic frameworks for immersive learning design remain scarce [16]. This highlights the need to develop structured design considerations tailored to VR-based engineering education, ensuring both usability and pedagogical alignment.

This study is an independent research phase within an ongoing longitudinal design-based research (DBR) project aimed at developing and refining a VR cleanroom training system for semiconductor education. Earlier phases of the DBR project identified several limitations in the initial prototype (*VR Cleanroom 1.0*), such as issues related to computing performance, user comfort, and instructional design [17]. In response, a revised version of the system (*VR Cleanroom 2.0*) was developed, incorporating updated technologies and design enhancements to address these challenges. Initial pilot study of VR Cleanroom 2.0 showcases the instructional potential of this application, while challenges specific to the adaptivity of learning and acclimation of the technology remained [6], indicating that further investigation and continued system refinement are necessary. The purpose of the current study is to evaluate *VR Cleanroom 2.0* by collecting user data that can inform its ongoing refinement. Specifically, the objectives are to: (1) evaluate and refine the VR cleanroom 2.0 through think-aloud protocol (TAP) sessions with domain experts, and (2) propose a preliminary, systematic set of design considerations to guide future iterations of the system. Research questions include:

RQ1: How do participants perceive the usability of VR Cleanroom 2.0?

RQ2: What insights can be drawn from participants' experiences to inform the re-design of VR Cleanroom 2.0?

2 Background

2.1 Virtual Reality for Engineering Lab Training

Oftentimes for engineering lab experiments and training, there are challenges and risks. First, lab activities are limited due to the availability of resources, such as, funding, space, adequacy of equipment, and personnel [5]. Second, the potential safety hazards due to the mistakes or malfunction [18]. The integration of VR technology in engineering lab training presents a transformative opportunity for maximizing access to the lab operation practices and reduced the significant hazards [18, 19].

A range of VR applications for engineering labs has been reported in the literature. For example, [20] presented a VR laboratory for earthquake engineering education. Results indicated high effectiveness for aiding students in understanding concepts and for visualization and interpretation of results. In electronics, [21] introduced a VR system that familiarized learners with laboratory hardware prior to physical use, reporting increased confidence, motivation, and reduced anxiety related to equipment malfunction. [22] presented a virtual laboratory (VL) designed to simulate a concrete laboratory environment. Students who utilized VL spent significantly less time completing the tasks in physical laboratory. More recently, [23] presented a VR laboratory for material science and mechanics, demonstrating its effectiveness in improving conceptual understanding and engagement. [6] also emphasized the benefits of embodied VR interactions in engineering labs, where congruence between physical movements and virtual learning tasks enhanced knowledge transfer. Echoing these findings, [13] highlighted that VR enables repeated practice of complex procedures without the danger of accidents or costly errors.

To date, research on VR applications for semiconductor fabrication remains scarce. Initial efforts include [24], who introduced the design and development of a VR simulations for photolithography, and [25], who developed an immersive VR-based training environment replicating the process. Complementary studies have begun to analyze user errors, completion times, and post-session feedback [26], as well as initial learning performance outcomes [6]. Emerging works, such as [27], demonstrate that immersive VR cleanrooms can reinforce students' understanding of nanoelectronics and semiconductor processes, yet systematic investigations into usability, instructional design, and iterative improvement remain limited.

2.2 Usability Studies and Design for VR-based Engineering Training

Usability is a quality attribute that indicates how easy to use the system or the prototype is [28]. Effectively evaluating a system's usability is critical, as it provides insights that can enhance the user experience and improve the system's overall functionality.

Within VR-based engineering training, a considerable body of research has addressed usability evaluation, with most evaluations relying on standardized questionnaire-based and interviews, [13, 29–32]. While these retrospective methods, such as the System Usability Scale [33], the User Experience Questionnaire [34], and user interview [35], provide valuable insights into learners' perceptions, they inherently limit the ability to capture real-time user interactions and their perceptions toward a specific interaction or design at the very moment.

In addition, there is a knowledge gap regarding the actionable design of VR environments that effectively balance interactivity and instructional design to maximize educational benefits. Some suggested higher immersion facilitates a better understanding of complex concepts and procedure [5, 23]; some suggested the need to manage cognitive load and information structure [36]; some recommended enriched information and guidance aids to help trainees develop a mental model of tasks to facilitate better understanding and retention [6]. While all these findings were valuable, very few studies present design considerations in a systematic and actionable format that can consistently guide both practice and future research. One earlier effort by Gavish and colleagues [37] outlined design guidelines emphasizing opportunities for observation, cognitive and physical fidelity, guidance, and enriched information. Yet, these guidelines were neither empirically validated nor structured systematically, which limits their practical applicability.

3 System Design

In this section, we outline the architecture and environment of the VR Cleanroom system, as well as the instructional design for the learning module.

3.1 System Architecture and VR Environment

To accurately design the VR training system, the research team worked together with the Electrical Engineering and Computer Science (EECS) domain experts and carefully examined and analyzed the lab equipment and procedures. The VR Cleanroom was built via Unity 3D, along with Virtual Reality Tool Kit (VRTK) to support both controller-based and gesture-based interactions. All 3D assets and lab equipment in the VR were custom-designed and modeled using Maya and Blender software to ensure high-fidelity realism. The VR experience was delivered via Meta Quest 2 head-mounted display (HMD).

To initiate the VR Cleanroom experience, users wore the HMD to enter the experience. For safety and proper user interaction, a physical boundary was first defined within the real-world environment. This spatial boundary ensured users remained within a safe area while allowing full freedom of movement inside the virtual environment. Once the boundary was established and the users had put on the VR headset, the experience began with a welcome screen, where learners input their names to allow the system to track individual progress. Users were then guided into a pre-lab warm-up area designed to help them become familiar with the VR controls and the virtual versions of lab equipment. This orientation included instructional video tutorials and hands-on practice exercises aimed at building users' confidence in operating VR interfaces and tools.

After completing the warm-up session, learners proceeded through a virtual exit into the main lab training module, where they were introduced to the photolithography process. This module included interactive, step-by-step tutorials for each laboratory device involved in the procedure. A virtual notepad guided learners through the process, providing detailed instructions, embedded quizzes, and real-time feedback. This design supported a self-paced, autonomous learning experience, adapting to each user's individual progress (see Fig.1 below).

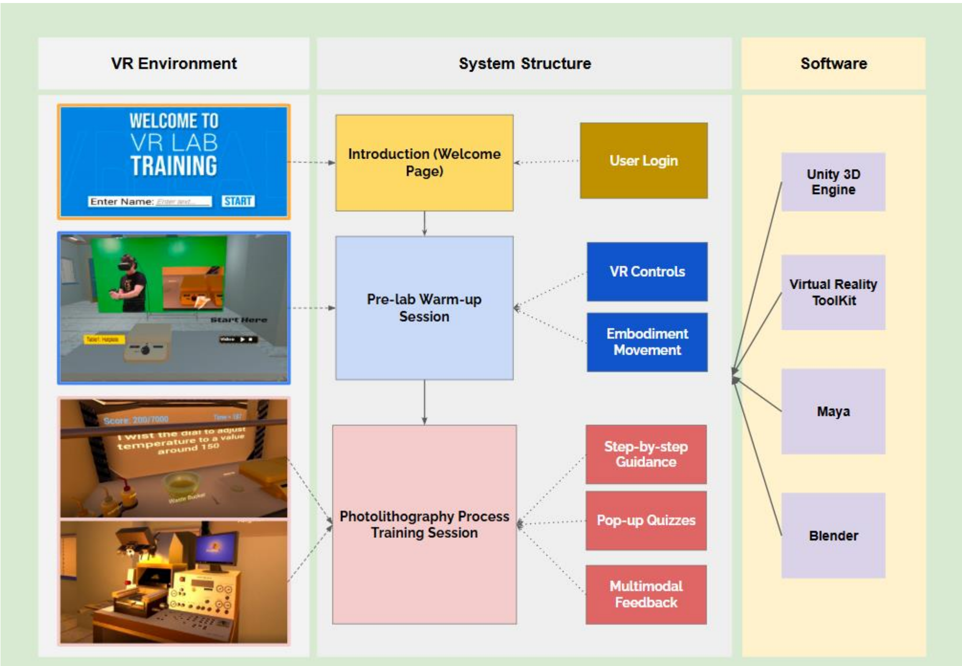

Fig. 1. System architecture and environment of the VR cleanroom system.

3.2 Learning Design

To ensure learning tasks are manageable and meaningful to the novice learners, we adopted Cognitive Theory of Multimedia Learning (CTML) [38] into our learning designs. Specifically, we broke down a long list of operations into four major sections, along with small steps with each section, to accommodate the memory load for the learners (see Table 1). Meanwhile, we have implemented scaffolding that allows learners to start from a prelab warm-up session, then proceed to a guided lab training session, and finally enter the independent learning session in which they complete the lab procedures by themselves. According to van Nooijen and team [39], scaffolding helps learners handle complex tasks by gradually adjusting the level of support, so they can manage their mental effort more effectively. Following CTML, we divided the photolithography process into four major procedures (see Fig. 2 below).

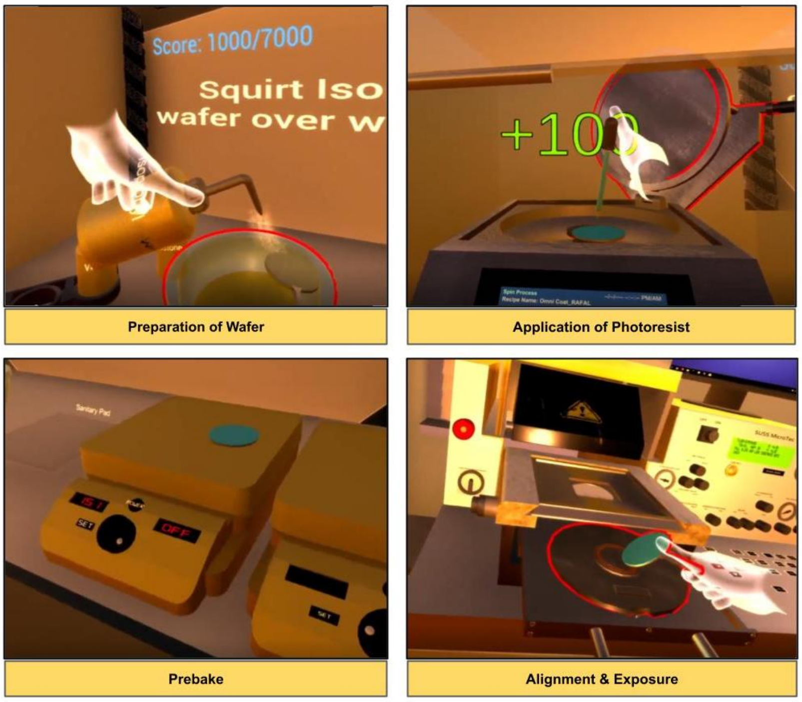

Fig. 2. Overview of the photolithography process in the VR cleanroom experience.

Table 1. Photolithography process and corresponding tasks.

Process	Specific Tasks
Step 1: Preparation of Wafer	1) Use tweezer to pick up wafer and hover the wafer above a waste bucket
	2) Flush wafer with Acetone, deionized
	3) Dry the wafer with nitrogen gun
Step 2: Application of Photoresist	4) Place the wafer holder in the spin coater, then place the wafer on top of the holder
	5) Extract photoresist with pipette and apply photoresist on to the wafer
	6) Select a recipe and spin coat the photoresist in the spin coater
Step 3: Prebake	7) Turn on the hotplate power and press the "set" button
	8) Turn the dial to set temperature to 150◦ and wait for heating
	9) Place the wafer on the hotplate for baking
Step 4: Alignment and Exposure	10) Turn on the mask aligner and configure the alignment parameters
	11) Put the wafer on a vacuum and lock the vacuum
	12) Adjust the microscope of the mask aligner to align the wafer with a mask
	13) Expose the wafer under the UV light

4 Methods

4.1 Study Design

This study is part of an ongoing iterative design and evaluation process of the VR cleanroom system. In this paper, we present the design, development, and evaluation of the second prototype of VR cleanroom. Our study employed think-aloud protocol, to gather real-time and retrospective feedback on the system. A hybrid method, including both concurrent and retrospective think-aloud, was utilized in the study [9, 10].

At the beginning of the VR learning session, participants were provided with a list of tasks to complete (see Table 1 above). While performing these tasks within the VR environment, they were required to verbalize their thoughts, observations, or experiences in real-time. After the VR session, participants were then engaged in a retrospective think-aloud session, during which they reviewed a recording of their VR experience and reflected on it. The entire study took approximately 60 mins.

4.2 Participants

A total of six participants (3 female, 3 male) were recruited through purposive sampling in collaboration with the Electrical Engineering and Computer Science (EECS) department at a Midwestern university. The participants were a group of senior researchers in the field of electrical engineering and were chosen for the study due to established technical proficiency in the photolithography process. The participants had an average age of 31.5 years and included three individuals identifying as Asian/Asian American and three as White/Caucasian.

4.3 Data Source and Analysis

Multiple data sources were used for understanding the usability of the current prototype. This include observation notes and think-aloud feedback.

Observation Notes
During the VR sessions, two researchers recorded detailed observation notes to document participants' comments and reactions to each specific task. As supported by Phillippi and Lauderdale [40], the inclusion of observational data provides valuable contextual insights into user experiences and real-time interactions with the system.

Think-aloud Data
Qualitative data was collected through both concurrent and retrospective think-aloud sessions. All verbal feedback was audio-recorded and transcribed for analysis. Data were analyzed using a combined approach: deductive coding based on Nielsen's usability heuristics [41, 42], and inductive coding approach to capture emerging categories not encompassed by the heuristic framework [43].

5 Results

In this section, we present the results of the think-aloud study, highlighting experts' perceptions of the ease of use of the VR Cleanroom learning system. The majority of identified usability issues and concerns were effectively categorized using Nielsen's usability heuristics, providing a structured lens for analysis. However, the data also revealed several additional challenges that fall outside the scope of Nielsen's usability frameworks, specifically, issues related to the learning design of the system. To improve the usability of the prototype, participants also provided suggestions.

5.1 Usability Issues

The identified usability issues were organized into 12 distinct categories (see Table 2). Participant labels (P1 through P6) are used throughout to show which participants experienced or reported any usability issue, as not all issues were encountered by every participant. Several noted Visibility of System Status issues such as system failed to inform them of object status (P2, P3, P4, P5). Users also reported unrealistic VR gestures, particularly in tool handling and interactions like knob turning, reflected on Match between System and Real-World issue (P2, P3, P4, P5). The category of User Control and Freedom included concerns about the inability to replay tutorial videos once skipped (P2, P3, P4, P5), while Consistency and Standards issues involved inconsistent visual cues between pre-lab and real lab environments (P2, P3).

For Error Prevention, users highlighted accidental tutorial skipping due to the lack of a way to go back (P3, P4, P5). Recognition Rather Than Recall challenges were evident as some participants struggled to map controller buttons to in-VR functions (P2, P4). Flexibility and Efficiency of Use was a recurring issue, with many users finding the basic VR movement controls difficult to manage (P1, P2, P3, P4, P5, P6). In terms of Aesthetic and Minimalist Design, unnecessary decorative machines caused confusion (P3). The Help Users Recognize, Diagnose, and Recover from Errors category captured issues like the absence of error notifications when tracking was lost (P5). Under Help and Documentation, users noted they were unsure how to access tutorial materials (P2, P3, P4, P6). Instructional Delivery focused on unclear guidance after task completion (P1, P2, P3, P4, P5, P6), and finally, Instructional Feedback and Assessment issues involved confusion over the emoji-based scoring system used in final evaluations (P2).

To better understand the distribution of these issues among participants, we then calculated the participant-based frequency for each usability category, representing the number of participants who reported at least one issue within each category (See Fig. 3 below). In total, 50 instances were recorded across all categories.

Instructional Delivery and Flexibility and Efficiency of Use emerged as the most frequently reported categories, with issues noted by six participants each (each accounting for 12% of usability concerns). This was followed by Match Between System and the Real World, Recognition Rather Than Recall, and Visibility of System Status, each reported by five participants (each accounting 10%). Additionally, Help Users Recognize, Diagnose, and Recover from Errors, Help and Documentation, and User Control and Freedom were each reported by at least four participants (each accounting 8%). Aesthetic and Minimalist Design, Instructional Feedback and Assessment, and Error Prevention were each reported by three participants (each accounting 6%). And lastly, at least two participants reported usability issues related to consistency and standards (each accounting 4%).

Table 2. Usability issues.

Categories	Usability Issues Examples	Participants' Quotes Example
1. **Visibility of System Status**	Object status was not informed (e.g., empty IPA bottle, sound effect delay) (P2, P3, P4, P5).	"I cannot tell if the power is on or not. There is a need for better visual indicator (P4)"
2. **Match between System and the Real World**	VR gestures lack proper physical realism (e.g., knob control, dropping tweezers) (P2, P3, P4, P5).	"In the real world, I can use my hands; but in the VR, the use of controllers felt unnatural to me… Very awkward (P5)"
3. **User Control and Freedom**	No way to replay the tutorial video once it is finished (P2, P3, P4, P5).	"I wanted to watch the tutorial video again. But it did not allow me to (P4)"
4. **Consistency and Standards**	Confusion due to inconsistent highlights in pre-lab sessions and training sessions (P2, P3).	"Why are visual indicators different between pre-lab and the in-lab experience? One is only yellow; another one is yellow and red together (P3)"
5. **Error Prevention**	Users clicked "Next" too fast or misinterpreted icons but couldn't go back to the previous step (P3, P4, P5).	"Oh no. I accidently hit the next button and could not go back. What do I Do? (P3)"
6. **Recognition rather than Recall**	Users could not associate the button on the controllers with the operation in the VR world (P2, P4).	"I cannot remember which one is Trigger button, which one is Grab button (P2)"
7. **Flexibility and Efficiency of Use**	Users struggled with basic VR movement control (P1, P2, P3, P4, P5, P6).	"I am not sure how do I move around with the controllers… I felt a bit dizzy when moving. Are there any other ways to move around (P1)?"
8. **Aesthetic and Minimalist Design**	Additional machines or objects presented in the VR for decoration purposes, which are not used in real labs (P3).	"Some decorations in the VR can be removed as you are not using them for learning (P3)"
9. **Help Users Recognize, Diagnose & Recover from Errors**	No warning or error message to notify or recover from lost tracking in the VR (P5).	"I lost my pipette... I don't know where I lost it and how can I get it back (P5)"
10. **Help and Documentation**	Users did not know how to launch the tutorial materials (P2, P3, P4, P6).	"How do I play the tutorial video? (P2)"

11.	**Instructional Delivery**	Unclear direction on what to do after completing the current step (P1, P2, P3, P4, P5, P6)	"Where do I start now in the pre-lab area? I cannot find direction to tell me where to start or what to do (P6)"
12.	**Instructional Feedback and Assessment**	Emoji-based scoring scale in the final report could be confusing to understand the learning performance (P2).	"I am not sure the meaning of those emojis on the screen. Do they mean I did good or bad? (P2)"

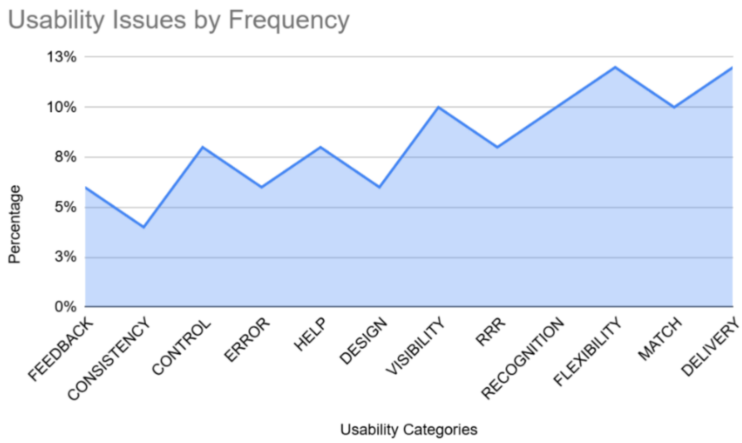

Fig. 3. Frequency distribution of usability issues by categories (*Note:* For readability purposes, the usability categories in this figure have been abbreviated using single-word labels. The full descriptions for each abbreviation are as follows: "FEEDBACK" means "Instructional Feedback and Assessment", "CONSISTENCY" refers to "Consistency and Standards", "CONTROL" refers to "User Control and Freedom", "ERROR" means "Error Prevention", "HELP" means "Help and Documentation", "DESIGN" means "Aesthetic and Minimalist Design", "VISIBILITY" means "Visibility of System Status", "RRR" means "Help Users Recognize, Diagnose, and Recover from Errors", "RECOGNITION" means "Recognition Rather Than Recall", "FLEXIBILITY" means "Flexibility and Efficiency of Use", "MATCH" means "Match between System and Real World", and "DELIVERY" means "Instructional Delivery").

5.2 Design Considerations

Bell and colleagues [44] outlined three levels of design principles of technology-enhanced environments: Specific Principles, Pragmatic Principles, and Meta-Principles. Following this approach, we exacted the data into a set of actionable design considerations for VR learning system design. Overall, a total of six meta-principles were extracted (See Table 3).

Table 3. Design considerations based on three-tiered design framework.

Meta-Principles	Pragmatic Principles	Specific Principles
System Transparency	1) Ensure system feedback is immediate and noticeable	Incorporate multimodal feedback (e.g., haptic, visual, auditory cues)
	2) Clear indications of the completed action and the next action	Position feedback elements within the user's primary field of view
		Use distinct visual indicators to signal completed actions and upcoming steps
Authenticity of the Environment	3) Align system models and interactions with real-world expectations	Enhance the realism, including accurate scale, appearance, and interaction mechanism
	4) Address safety protocol	Integrate safety elements, such as PPE preparation and correct disposal procedures
Pedagogical Alignment	5) Ensure instructional clarity	Use simple and clear language to avoid confusion and reduce cognitive load
	6) Deliver both conceptual and procedure knowledge	Pair procedural instructions with conceptual explanation to deepen understanding

	7) Provide feedback reflects on real-time learning performance	Provide real-time and meaningful feedback to help learners understand their performance
	8) Ensure structure learning path	Present instructions and procedures in a logical, step-by-step sequence Maintain consistency in layout, instruction style, and cues
Adaptive Support and Flexibility	9) Secure onboarding prior to official learning session	Enhance warm-up or tutorial areas to familiarize users with VR controls and tasks prior to real activity
	10) Reduce physical and cognitive efforts	Simplify complex inputs by avoiding the use of multiple buttons for a single action Reduce control sensitivity or allow broader input tolerances where precision is unnecessary
	11) Support flexibility during learning	Offer multiple locomotion options Enable users to choose their learning pace (e.g., accelerated, guided)
Simplicity and Focus	12) Remove non-essential elements to reduce distraction	Eliminate irrelevant models and content that do not serve a learning purpose
Error-Tolerant Learning	13) Provide contextual support to learners	Use tooltips, overlays, or in-VR assistance to explain controls, objects, or instructions in real time
	14) Integrate error recovery mechanism that allows users to reflect and retry	Include features such as preview interfaces and confirmation prompts before executing irreversible actions Implement progress tracking and "retry step" options to recover from mistakes without restarting

6 Discussions and Conclusions

The findings of this study indicate that usability issues in VR-based lab training extend beyond conventional interaction-level concerns typically addressed by Nielsen's usability heuristics. Many observed are deeply rooted in instructional design, particularly in the areas of instructional delivery, feedback, and assessment. This supports the growing recognition within the learner experience design field that traditional usability alone is insufficient for evaluating the overall quality of learning systems [45, 46]. Instead, there is a need to shift toward the concept of pedagogical usability as well as learning experience design (LXD), which emphasizes the alignment between interactive design and learning design [47, 48], thereby providing a more holistic understanding of learning system quality.

Accordingly, this study categorized the identified usability issues into 12 distinct types. Notably, issues related to *Instructional Delivery* and *Flexibility and Efficiency of Use* were reported most frequently, suggesting that users encountered friction not only with system interaction but also with how instructional content was structured and paced. These were followed by challenges in *Match Between System and the Real World, Recognition Rather Than Recall,* and *Visibility of System Status,* indicating concerns with realism, cognitive load, and system transparency within the VR environment.

In addition, this study summarized a preliminary set of design considerations intended to guide both designer and researcher in designing, developing, and evaluating a VR-based engineering lab training. Each consideration is accompanied by pragmatic descriptions and actionable examples, supporting the development of more effective and user-centered VR learning experiences. In the literature, while [49]'s work offers valuable theoretical and experiential insights into embodied learning in VR, her design recommendations are presented as broad guidelines with limited structural organization. Our design considerations build on and align with her principles, while offering a more systematic and operationalized approach. For example, our emphasis on onboarding, simplified UI, and guided tutorials reflects her recommendation to "start slow" and reduce cognitive and proprioceptive overload. Similarly, our principles of gesture congruence, instructional clarity, and error-tolerant learning align with her advocacy for intuitive physical interactions, UI decluttering, and reflective learning. By systematically organizing and extending these principles, our design framework addresses a gap in the current literature, which often lacks structured, theory-informed guidance for immersive learning environment design [37].

Moreover, many of the usability challenges observed are closely related to cognitive load, a key consideration in multimedia, human psychology, and instructional design. While the findings echo the principles outlined in the

Cognitive Theory of Multimedia Learning (CTML), such as reducing extraneous load and segmenting complex tasks [38], they also highlight more nuanced design challenges that are unique to interactive VR environments. In immersive settings, cognitive load is not only about content complexity but also about the mental effort required to interact with and make sense of the virtual world [50, 51]. Specifically, the empirical user data points to a need for designers to go beyond generic design principles and consider context-specific cognitive demands, such as how users navigate 3D space, interpret visual cues, and map physical gestures to virtual actions. As such, these findings reinforce the importance of an iterative design process that continuously integrates user feedback. This approach also allows for the refinement of both instructional strategies and interaction mechanisms, ensuring that VR-based learning environments are cognitively manageable, pedagogically sound, and user-friendly.

This observation aligns with [52]'s extension of CTML into immersive contexts. They emphasized the unique affordances of immersive media such as control, embodiment, and representational fidelity, and how they afford immersive experience. In our study, issues related to gesture-based control, visual overload, and physical navigation indicate that when these affordances are poorly supported, cognitive engagement and learning outcomes might be compromised. Similarly, the usability challenges identified in our study closely align with [49], who highlights that physical gestures must be congruent with the conceptual content being taught. In our system, participants frequently encounter difficulties with the control schemes, highlighting a lack of intuitive mapping between user actions and system responses. These findings suggest a clear need to improve gesture-content congruency to reduce user friction during interaction.

In this light, the use of TAP as a diagnostic method provides unique value: it captures not only surface-level usability issues but also exposes learner thought processes, confusion, and strategy use as they unfold. This contributes to a more nuanced understanding of how design and instruction interact in immersive learning context.

The next phase of this research will focus on the refinement of the current VR Cleanroom prototype, informed directly by the usability and instructional design issues identified in this study. Specifically, improvements will target high-priority concerns such as instructional sequencing, navigation design, and interaction realism, with the goal of enhancing both usability and learning efficacy. We also plan to conduct a formative evaluation with a group of end users. This will enable a more rigorous assessment of the prototype's instructional effectiveness. Data collection will expand to include quantitative measures such as task performance, error rates, and pre/post learning assessments, in addition to qualitative usability feedback.

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