Virtual Reality Orientation for Robotics Labs: Safe Entry, Spatial Rules, and Learning Outcomes

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Abstract

This study presents the development and evaluation of an immersive virtual reality (VR) orientation module designed to introduce students to a university robotics laboratory and familiarize them with physical lab sessions. The VR environment guides learners through key laboratory procedures, starting with putting on the required safety gear and adherence to established entry protocols. Within the simulation, students interact with various robotic systems, observe representative task demonstrations, and learn about the movement boundaries enforced by a spatial feedback system that warns users when they enter unsafe or restricted zones. The objective is to familiarize students with the physical lab's spatial layout, operational norms, and safety culture in a low-risk, engaging setting. Twenty-six participants experienced the developed VR environment and responded to standardized post-activity surveys measuring usability, user perceptions, learning outcomes, and comfort. Results show strong evidence of usability and educational value, with a mean System Usability Scale score of 80.08, significantly higher than the 68-point benchmark, indicating a user-centric system design. User-perception ratings were consistently above neutral (usefulness = 5.5, realism=5.96, comfort = 4.8 on a 7-point scale), while knowledge scores averaged 7.58/8, suggesting substantial learning gains regarding lab safety rules and robot types. No simulator sickness symptoms were reported in the pre- or post-session, demonstrating effective ergonomic and user-friendly design. Correlation analyses revealed a negligible negative association with prior VR familiarity, indicating that prior experience had little influence on perceived usability. Overall, the VR module provided an engaging, safe, and pedagogically effective orientation, strengthening students' confidence and procedural readiness for real-world robotics tasks. Future extensions will scale deployment across courses, integrate performance analytics, and examine behavioral transfer from the virtual to the physical laboratory.

Introduction

A skilled robotics workforce is essential to maintaining U.S. economic competitiveness and manufacturing leadership, making effective and safe robotics education a national priority. Robotics laboratories are a critical component of engineering education, but they introduce safety risks for novice students because articulated robots operate within task-dependent motion envelopes and restricted operating zones [1]. Understanding these hazards requires spatial and procedural awareness that is difficult to achieve through abstract instruction alone. Extended Reality has therefore been increasingly explored for safety training because it enables learners to experience realistic hazardous scenarios in a controlled environment without physical risk [1, 2].

In many university settings, laboratory safety orientation is commonly delivered through lectures, manuals, videos, or slide-based training, which effectively communicate rules but provide limited embodied understanding of spatial hazards and dynamic robot behavior. Recent studies have shown that immersive and virtual laboratory safety training can improve engagement and contextual understanding compared to traditional formats [3, 4]. However, adoption of Virtual Reality (VR) training depends on usability, perceived usefulness, and physical comfort, as cybersickness can reduce tolerance and willingness to reuse VR systems [5].

Accordingly, this work develops a VR robotics laboratory orientation environment that replicates an actual university robotics lab at the Rochester Institute of Technology to introduce students to laboratory rules, required personal protective equipment, articulated robot options, and common robot work tasks, while reinforcing safe behavior through contextual warnings. The study evaluates usability and acceptance using constructs from the Technology Acceptance Model (TAM) [6] to assess whether the VR environment is suitable as a preparatory tool for robotics laboratory safety training.

Background and Related Works

VR has been increasingly explored as a training and orientation tool in educational and industrial settings, particularly for tasks that require spatial understanding and interaction with complex environments. In higher education, immersive VR has been applied to laboratory instruction, engineering machinery training, and safety education [1, 2, 7]. Recent systematic reviews report that immersive VR can improve engagement, motivation, and learning outcomes compared to non-immersive instructional approaches when aligned with instructional objectives [2, 8]. However, prior work also emphasizes that VR effectiveness depends strongly on instructional and interaction design. Poorly designed immersive environments may increase cognitive load or distract learners from core learning objectives, especially in technical and safety-critical contexts [9].

A key barrier to VR adoption is cybersickness, which includes symptoms such as nausea, dizziness, and eyestrain caused by sensory conflicts in immersive environments. Cybersickness has been widely documented as a factor that can reduce user comfort and willingness to continue using VR systems [5]. Recent analyses of VR training programs further indicate that cybersickness directly influences user acceptance and that task design and exposure conditions modulate both discomfort and acceptance outcomes [10]. To understand adoption of educational technologies, many studies apply the TAM, which identifies perceived ease of use and perceived usefulness as primary determinants of behavioral intention to use a system [6]. Recent empirical studies confirm that TAM constructs remain significant predictors of learners' intention to adopt VR-based educational systems, supporting the model's applicability to immersive learning contexts [11, 12]. Usability assessment is therefore a central component of VR training evaluation. The System Usability Scale (SUS) [13] is a widely used standardized instrument that provides a global measure of perceived usability based on user ratings of effectiveness, efficiency, and satisfaction [14]. SUS has been extensively used in VR and training research to benchmark usability and support comparative evaluation across systems [15].

Together, existing work supports the use of VR for educational training in spatially complex and safety-critical environments, while highlighting the importance of evaluating usability, acceptance, and cybersickness alongside learning outcomes. These considerations motivate the present study's focus on developing and evaluating a VR robotics laboratory orientation environment using theory-grounded acceptance measures, comfort monitoring, and learning performance assessment.

Objective and Research Questions

The objective of this study is to develop and evaluate a VR robotics laboratory orientation and safety training environment that replicates an actual university robotics lab and prepares students for safe participation prior to entering the physical laboratory. The VR environment introduces laboratory rules, required personal protective equipment, articulated robot types, and common robot work tasks, while reinforcing safe behavior through contextual warnings when users enter hazardous operating zones. To assess whether the VR environment is suitable as a preparatory training tool, the study addresses the following research questions:

- RQ1. To what extent do usability and user experience factors support participants' acceptance of VR as an effective tool for robotics laboratory orientation and safety training?

- RQ2. Does participation in the VR laboratory orientation result in acceptable levels of simulator sickness while supporting effective learning outcomes related to laboratory safety and robot task awareness?

These research questions are aligned with the usability, user experience, simulator sickness, and learning outcome measures collected in the study.

Methodology

This section outlines the development-and-evaluation methodology used in the study, including the design of the VR robotics lab orientation system and its assessment through a controlled user study. Guided by the Technology Acceptance Model, it describes the research design, participant procedures, and data collection methods used to evaluate usability, user acceptance, physical comfort, and learning outcomes.

Study design and research framework

This study adopts a development-and-evaluation research design in which a VR robotics laboratory orientation environment was developed and then evaluated through a controlled user study. The purpose of the evaluation is to determine whether the VR environment is suitable as a preparatory tool for robotics laboratory orientation and safety training. The evaluation considers user acceptance and usability, physical comfort and simulator sickness, and learning effectiveness. To structure the evaluation of acceptance-related outcomes, the study is guided by the TAM [6], which explains technology adoption through perceived ease of use and perceived usefulness. In this study, perceived ease of use is operationalized through system usability measurement, while perceived usefulness and overall experience are captured through post-experience perception ratings. Because VR systems impose physical and perceptual demands, simulator sickness is explicitly assessed as a feasibility factor, and learning outcomes are included to evaluate instructional effectiveness.

Hypothesis development

Based on research questions and the TAM-informed framework, hypotheses were formulated to evaluate technology acceptance, safety and comfort, and learning effectiveness. The hypotheses are grouped into two categories corresponding to the two research questions. Table 1 describes the hypotheses and evaluation focus of this study.

Table 1. Hypotheses and evaluation focus

Category	Hypothesis ID	Hypothesis Statement	Related Measure(s)
Technology Acceptance and Usability	H1a	The VR training system will achieve a SUS score significantly above the standard acceptability benchmark of 68	SUS
	H1b	Participants will report perceived usefulness of the VR training system significantly above a neutral rating	User-perception survey
	H1c	Participants will report perceived comfort with the VR system significantly above a neutral rating	User-perception survey
	H1d	System usability will not be negatively associated with participant age or prior familiarity with VR technology	Demographic survey, SUS
Safety, Comfort, and Learning Effectiveness	H2a	Simulator sickness severity following VR exposure will not increase to levels indicating unacceptable discomfort	VRSQ (pre/post)
	H2b	Participants will demonstrate knowledge performance significantly above a predefined proficiency threshold	Knowledge survey
	H2c	Participants will report positive perceptions of the VR system's effectiveness for learning robotics safety concepts	User-perception survey

VR environment development

The VR environment was developed in Unity [16] and deployed on the Meta Quest 3 [17] to replicate the layout and functional elements of an actual university robotics laboratory, with the goal of preparing students for safe laboratory participation prior to entering the physical lab. As illustrated in Figure 1, participants first enter the VR environment through a staging area where they are guided to wear the required personal protective equipment (PPE), such as protective gloves, goggles, and helmets. The system prevents entry into the robotics laboratory until the PPE protocol is fully satisfied. Once inside the lab, participants are free to move around and observe the laboratory layout and available articulated robots; if a participant enters a robot's operating zone while the robot is active, a contextual virtual warning is triggered to indicate that the area is hazardous and that remaining in the zone is unsafe. Participants can then access an interface inside the virtual environment to select different articulated robots and view their components, followed by a dropdown menu to choose task types associated with each robot. Upon task selection, the simulation demonstrates how the robot performs the selected operation, such as pick-and-place, welding, or drawing geometric shapes. After exploring the robots and their functions, participants exit the VR environment, completing the orientation experience.

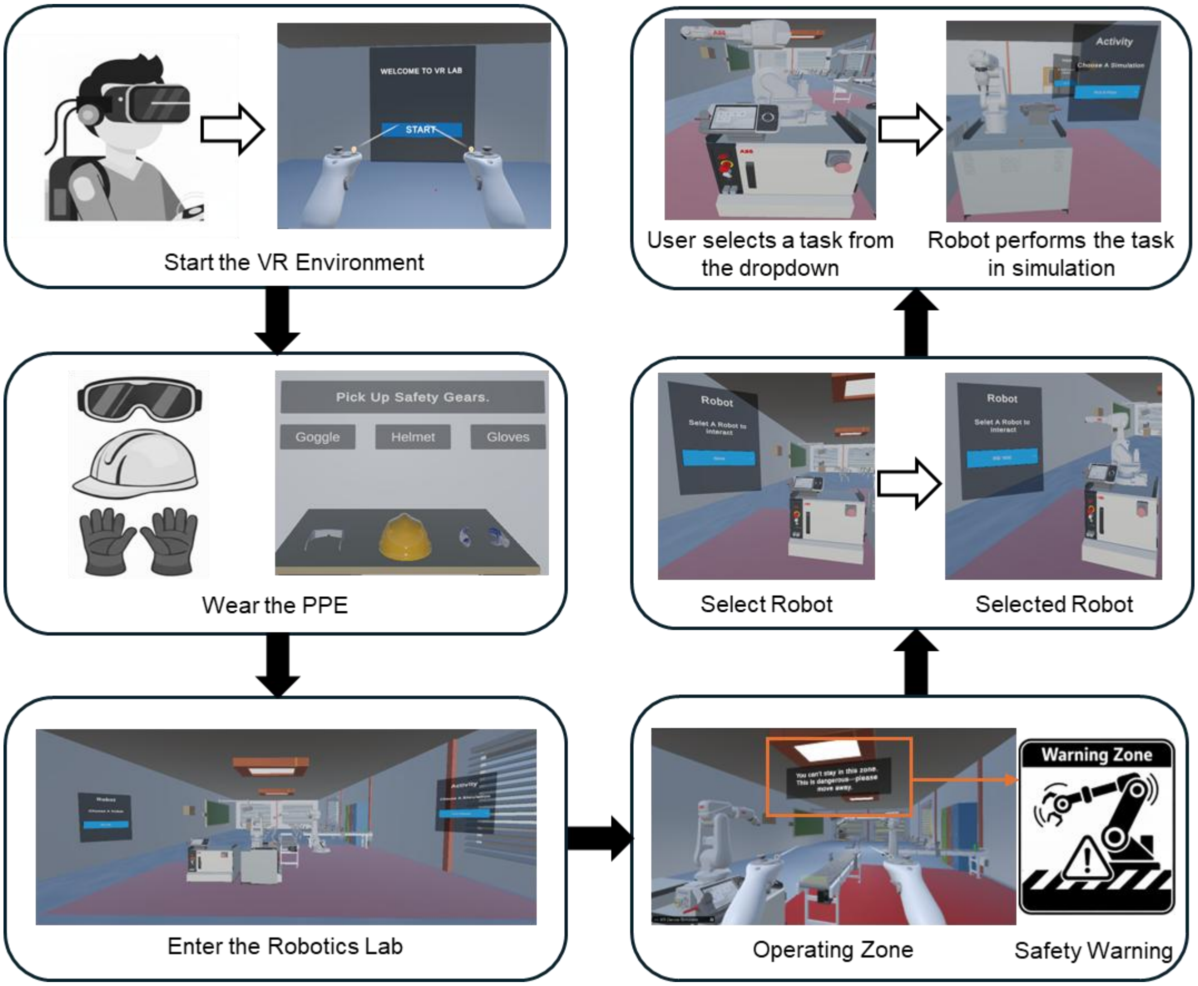

Figure 1. Workflow diagram of VR experience.

Participant procedure and data collection

Participants were recruited from an academic setting and took part in the study one at a time. Before starting the virtual reality (VR) session, each person completed an IRB-approved consent process and a demographic survey that asked about age, gender identity, and experience with VR technology. The Virtual Reality Sickness Questionnaire (VRSQ) was given to record any simulator sickness symptoms before the session. After confirming eligibility, the researcher showed how the VR system worked by sharing the headset view on a mobile device and explaining how to use the controllers. Participants then used the headset themselves and went through the VR lab orientation at their own pace. Right after the VR session, the VRSQ was given again to check for any new simulator sickness symptoms. Participants then filled out the rest of the post-experience surveys, including the System Usability Scale (SUS), a user-perception survey on usefulness, comfort, and learning, and a knowledge survey about robotics lab safety and task concepts. Figure 2 shows the full data collection process, including onboarding, baseline assessment, VR use, and post-experience surveys.

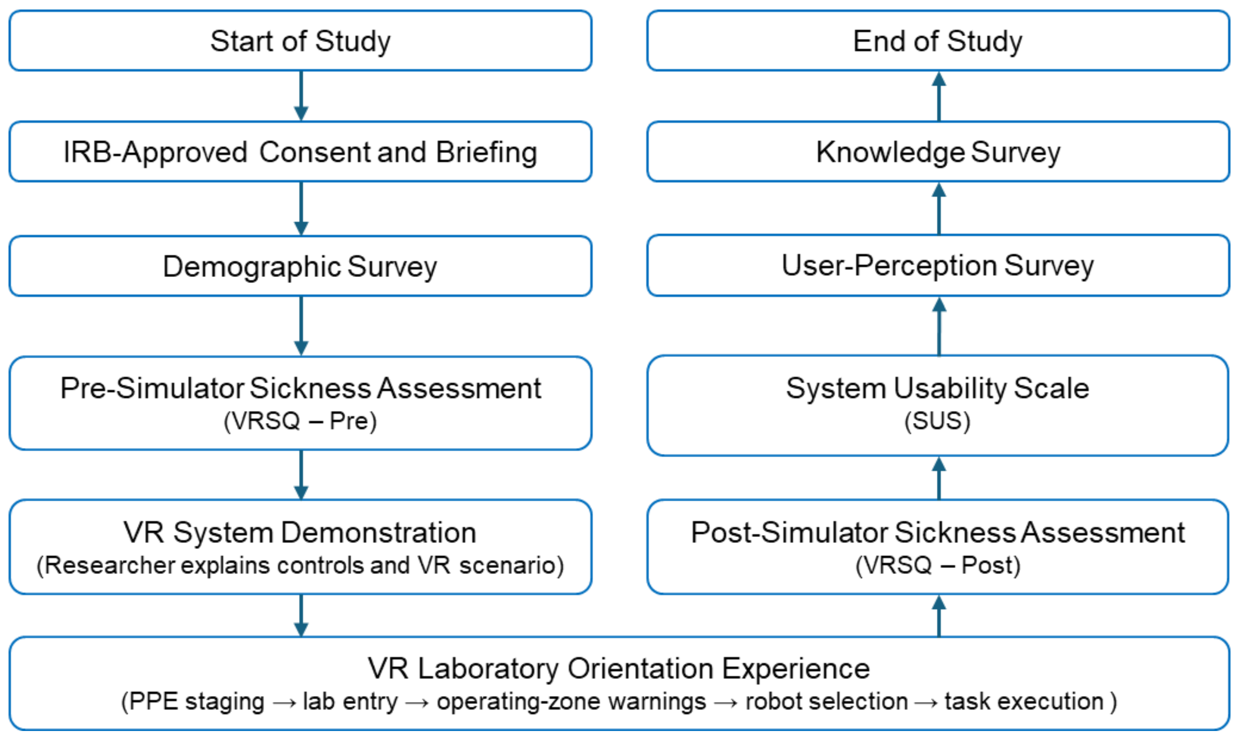

Figure 2. Data collection procedure

All measures used in the study directly align with the research questions and hypotheses. Table 2 summarizes the instruments, constructs measured, scale characteristics, and timing of data collection.

Table 2. Measures and data collection summary

Instrument	Construct Measured	Scale / Output	Timing
Demographic survey	Age, gender identity, VR familiarity	Categorical/numeric	Pre-VR
VRSQ	Simulator sickness severity	Severity score	Pre- and Post-VR
SUS	Perceived ease of use / usability	0-100	Post-VR
User-perception survey	Usefulness, comfort, perceived learning effectiveness	1-7 Likert	Post-VR
Knowledge survey	Robotics safety and task understanding	Score-based	Post-VR

Results

Data from $N = 26$ participants were included in the analysis. Participants were primarily undergraduate students, with a mean age ($M = 21.08, SD = 1.20$), ranging from 19-24 years. Self-reported gender identity was predominantly male ($n = 23$), with female ($n = 2$) and other ($n = 1$) participants also represented. Most participants reported prior familiarity with VR ($Yes = 24$; $No = 2$), with a mean self-reported familiarity level ($M = 4.54$) on a 7-point scale. Figure 3 presents the distribution of participant demographics. Statistical tests were selected based on the measurement scale and study design. One-sample t-tests were used for continuous outcomes compared against established benchmarks [18, 19]. Wilcoxon signed-rank tests [20] were used for ordinal Likert-scale data and paired pre/post simulator sickness comparisons due to non-normality and bounded scales. Spearman rank-order correlations [21] were used to examine associations between usability and demographic variables. All hypothesis tests were conducted at an alpha level of $\alpha = 0.05$. Directional hypotheses were evaluated using one-tailed tests, while non-directional association tests used two-tailed tests, consistent with standard statistical practice [22].

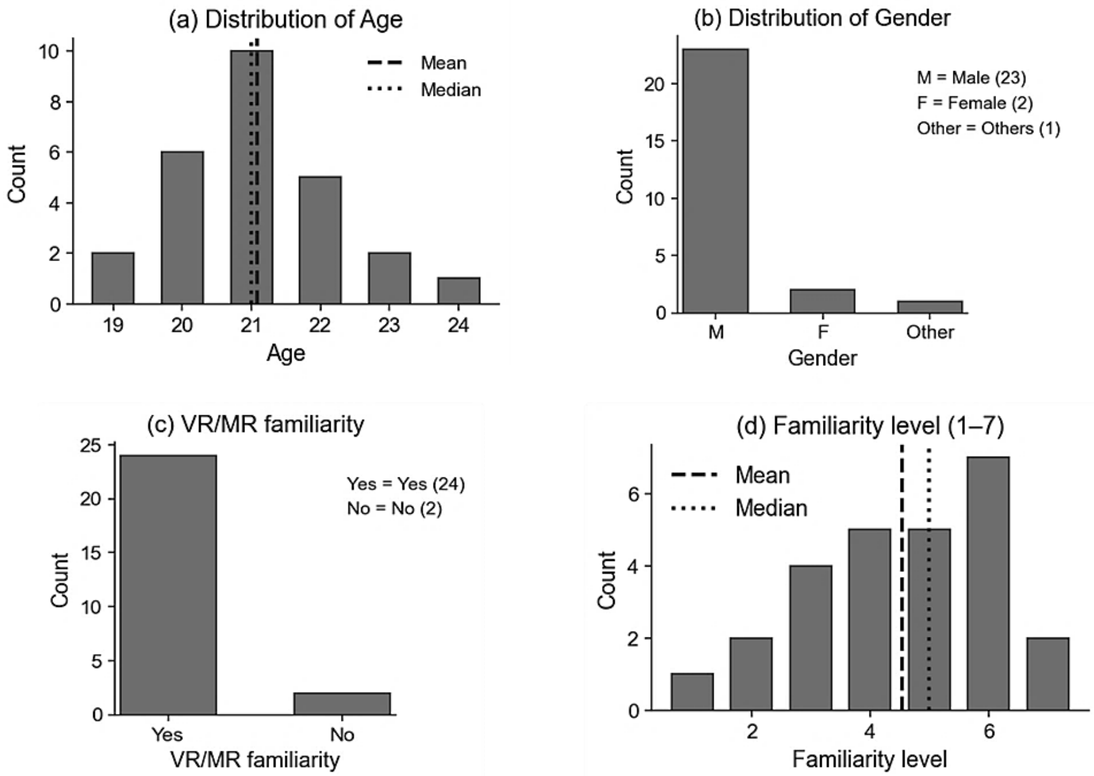

Figure 3. Distribution of participant demographics, including (a) age, (b) gender identity, and prior VR or AR familiarity, shown both (c) categorically and by (d) familiarity level.

Technology Acceptance and Usability (H1a-H1d)

Usability was assessed using the SUS, a cumulative instrument ranging from 0 to 100 based on 10 Likert-scale items. To calculate the final score, responses are normalized by subtracting 1 from positively worded items and subtracting the response value from 5 for negatively worded items; these adjusted scores are then summed and multiplied by 2.5. One participant was excluded from this analysis due to missing data for the SUS items. Participants reported high perceived usability for the VR laboratory orientation, with a mean SUS score ($M = 80.80$, $SD = 7.83$). A one-sample, one-tailed t-test was conducted to test whether the observed mean usability exceeded the commonly used SUS acceptability benchmark of 68 [23], which represents average usability across systems. The test was statistically significant, $t(24) = 8.17$, $p < 0.001$, indicating participants perceived the VR system as highly usable, supporting H1a. Perceived usefulness and perceived comfort were measured using 7-point Likert-scale items included in the user-perception survey. Because Likert-scale responses are ordinal, one-sample Wilcoxon signed-rank tests were used to compare median ratings against the neutral midpoint value of 4. Participants rated the usefulness of the VR application ($M = 5.50$) and the realism of the physical laboratory structures ($M = 5.96$) significantly above the neutral midpoint ($p < 0.05$), based on one-tailed tests, supporting H1b. Perceived physical comfort ratings ($M = 4.81$) were also significantly greater than neutral ($p < 0.05$), based on a one-tailed test, supporting H1c and suggesting that the system is feasible for short instructional use. To examine whether usability varied across participant characteristics, two-tailed Spearman rank-order correlations were computed between SUS scores and participant age, and between SUS scores and prior VR familiarity. No statistically significant associations were observed between SUS and age ($Spearman's\ \rho = -0.24, p = 0.24$) or between SUS and prior VR familiarity ($\rho = -0.11, p = 0.59$), supporting H1d. These findings indicate that usability perceptions were consistent across participants with differing demographic backgrounds and levels of prior immersive technology experience.

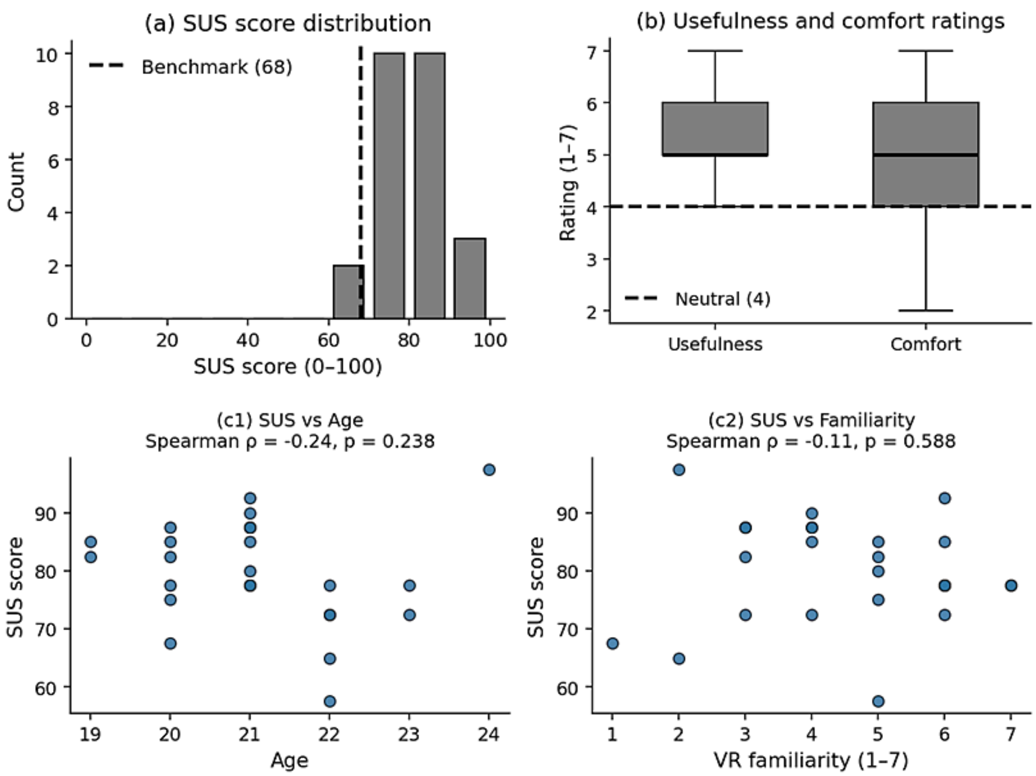

Figure 4. (a) Distribution of SUS scores; (b) perceived usefulness and comfort ratings relative to the neutral point; (c) relationships between SUS scores and participant age and prior VR familiarity.

Figure 4 summarizes the results related to H1a-H1d. Figure 4(a) shows the distribution of SUS scores across participants with the benchmark value of 68 marked; the histogram indicates that most observed SUS scores lie above the benchmark, visually reinforcing that usability exceeded average acceptability. Figure 4(b) presents boxplots of perceived usefulness and perceived comfort relative to the neutral midpoint (4), showing that median ratings for both constructs are above neutral with limited dispersion, consistent with statistically significant one-sample comparisons. Figure 4(c) plots SUS scores against participant age and prior VR familiarity with Spearman correlation coefficients annotated; the scattered patterns show no clear monotonic trend, supporting the conclusion that usability perceptions were broadly consistent across age and prior immersive-technology experience.

Simulator Sickness and Learning Effectiveness (H2a-H2c)

Simulator sickness was assessed using the VRSQ administered before and after VR exposure. Because VRSQ scores are bounded and may be not normally distributed, a paired Wilcoxon signed-rank test was used to evaluate changes in symptom severity. Baseline sickness levels were low ($pre-VR$: $M=0.69$, $median=0$), and post-exposure scores increased modestly ($post-VR$: $M=1.81$, $median=1$). The increase was statistically significant ($p<0.05$), based on a one-tailed test, indicating that some participants experienced increased symptoms. However, absolute severity levels remained low for most participants, with the majority reporting no or mild symptoms. Because the VRSQ does not define a universal clinical cutoff, results are interpreted based on magnitude and distribution rather than a strict acceptability threshold. These findings provide partial support for H2a, suggesting acceptable sickness levels for most users while highlighting the importance of monitoring discomfort.

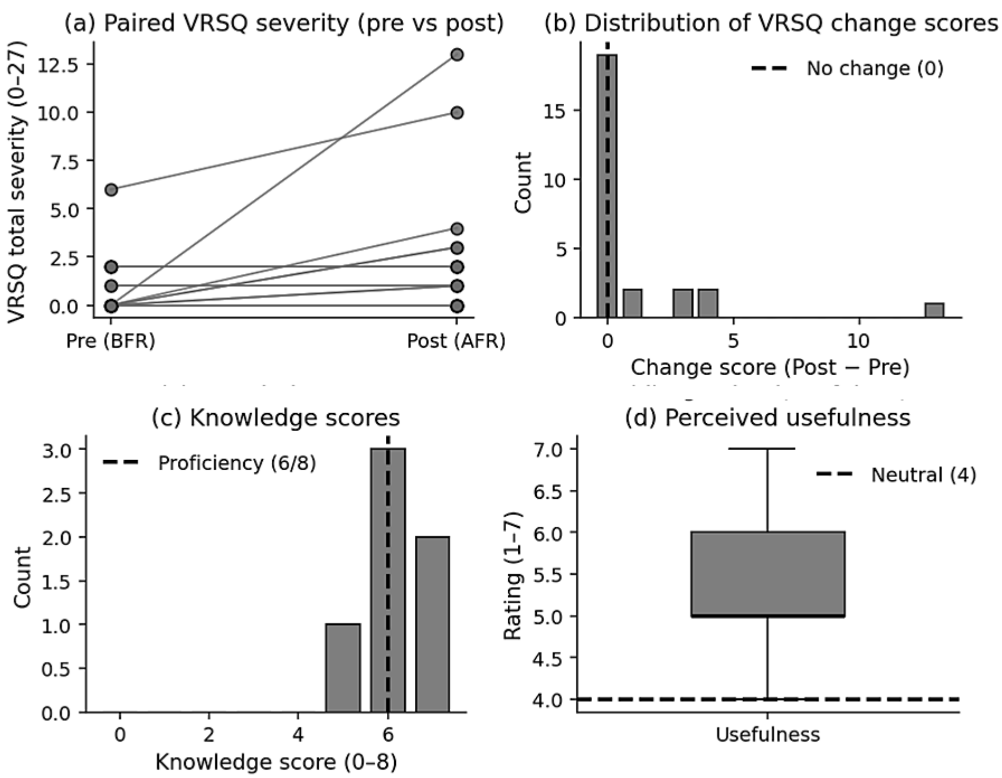

Figure 5. Simulator sickness and learning outcomes: (a) Pre-post VRSQ severity; (b) VRSQ change scores; (c) knowledge scores with proficiency threshold; (d) perceived learning effectiveness.

Learning effectiveness was evaluated using an 8-item post-training knowledge survey aligned with the VR orientation objectives. Participants achieved high scores ($M=7.58, SD=0.86$). A one-sample, one-tailed t-test showed that mean performance exceeded a predefined proficiency threshold of 6 out of 8 (75%), $t(25)=9.39,\ p<0.05$, supporting H2b. The score distribution showed a ceiling tendency, indicating that the VR orientation effectively conveyed foundational laboratory safety and robot awareness concepts. Subjective learning effectiveness (H2c) is further supported by user-perception ratings reported above.

Figure 5 summarizes the outcomes related to H2a-H2c. Figure 5(a) presents a paired slope plot of pre- and post-exposure VRSQ total severity scores for each participant, highlighting within-participant changes and showing that most participants experienced reduced simulator sickness after the VR session. Figure 5(b) shows the distribution of VRSQ change scores (post minus pre), indicating that the majority of participants exhibited negative change values, corresponding to decreased sickness severity. Figure 5(c) illustrates the distribution of knowledge assessment scores with the proficiency threshold of 6 out of 8 marked, demonstrating that most participants achieved or exceeded the targeted proficiency level. When space permits, Figure 5(d) provides a compact boxplot of perceived learning effectiveness relative to the neutral midpoint, indicating that participants generally rated the VR experience as beneficial for learning.

Discussion

This study investigated how usable, acceptable, safe, and effective VR robotics laboratory orientation is for preparing students before they enter the real lab. The VR session covered laboratory rules, necessary protective gear, and common articulated-robot tasks before students' in-person experience. Overall, the results indicate that the VR environment was highly usable, instructionally effective, and generally well tolerated by participants.

The outcome from technology acceptance and usability (RQ1) shows that VR is a practical tool for robotics lab orientation. The mean SUS score was 80.08, well above the standard value of 68, and participants often described the system as useful (5.5 out of 7), realistic (5.96 out of 7), and comfortable (4.8 out of 7). Results for usability ratings did not depend much on age or previous experience with VR or AR. For example, participants rated the usefulness of the VR application above the neutral value (M=5.50, Neutral value=4). which means the system can help students regardless of their previous backgrounds. Overall, these results suggest that VR can help students become familiar with lab layouts, potential hazards, and common tasks before they enter a real lab. The findings for safety, comfort, and learning (RQ2) show that the VR orientation balanced teaching value with physical comfort. Some participants had a slight increase in simulator sickness symptoms after using VR $(pre - VR: M = 0.69, median = 0\ and\ post - VR: M = 1.81, median = 1)$, but most had low symptom levels, which aligns with earlier studies on short, mostly stationary VR sessions. Since the VRSQ does not set a clear cutoff, simulator sickness was judged by the frequency and severity of symptoms, not just whether they were acceptable or not. Participants suggest that designers should continue to focus on comfort, including session length, movement methods, and how users interact with the system. The learning results also show that the VR orientation was effective $(M = 7.58, SD = 0.86, t(25) = 9.39, p < 0.05)$. Participants performed well on the knowledge test after training and reported a positive learning experience. Because many scored highly $(M = 7.58, out\ of\ 8)$, it seems the VR environment clearly taught the basics of lab safety and robot awareness. However, harder tests may be needed as the lessons get more advanced.

This research has some limitations. The study used a small group from a single academic setting, with participants mostly in the same age range, and did not include a control group. This makes it hard to apply the findings widely or compare them directly to traditional lab orientations. Also, learning was measured right after the VR session, so we do not know how well knowledge lasts or transfers to real lab work. Finally, the VR environment focused on observation and procedures, not on operating robots, so we cannot say much about skill transfer to more complex tasks.

Future Work

Future work will include making the VR environment more interactive, allowing users to operate articulated robots, practice specific tasks, and follow task plans similar to real lab activities. Planned updates include scenarios like pick-and-place and welding, controls that match real equipment, training that adapts to each user, and multi-session courses that combine VR orientation, virtual practice, and real lab work. Future studies will also use controlled experiments, include more diverse participants, and track learning and safety over time. These steps will help build a complete VR training platform for robotics education.

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