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Development of a Virtual Reality Learning Environment for Computer Assembly Competency in Pre-Service Teachers Using Generative AI-Produced Media

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Abstract

Thai computer teacher trainees must assemble and repair computers during their practicum, yet many get little hands-on practice because laboratory machines are scarce, outdated, and easily damaged. This design-and-development study built a virtual reality learning environment (VRLE) for computer assembly on a Meta Quest 3 headset, with controller-free hand tracking, three simulation rooms mapped to a national occupational competency unit, and learning media produced with generative AI. Development followed the ADDIE model, and a feasibility tryout used a one-group pretest–posttest design. Three content experts and three technical experts rated content (M = 4.74) and technical quality (M = 4.45) as very good, with interaction and usability the weakest domain (M = 4.11). Among 35 pre-service teachers with matched tests, achievement rose from 8.20 to 9.09 out of 10 (Wilcoxon z = 2.95, p = .002, r = .50; t(34) = 2.92, dz = 0.49). After a sequence of website lessons, VR practice, real-hardware practice, and debriefing, mean competency on real hardware was 4.85 (n = 36) and mean satisfaction was 4.79 (n = 28), both with ceiling effects. Without a control group, the results show that the VRLE is feasible and well received, not that it caused the gains.

Keywords: virtual reality, generative AI, hand tracking, occupational competency standard, teacher preparation, feasibility study, computer hardware training

1. Introduction

1.1 The Problem in Context

Thailand's National Education Plan (2017–2036) relies on digital technology to widen access to education and to improve teaching (Office of the Education Council, 2017), but someone has to keep the machines working. In many Thai schools this is the computer teacher, who must repair computers and components that fail, usually with no technician to call.

The university where the study took place trains computer teachers in a Bachelor of Industrial Education program in Computer Technology, with a two-semester teaching practicum, 540 hours per semester, in the final year (King Mongkut's University of Technology North Bangkok [KMUTNB], 2021, pp. 12, 28). Student teachers are often put in charge of computer rooms, assembly, and troubleshooting, yet mentor teachers interviewed for the needs analysis reported that student teachers could not repair school computers without guidance and urged the department to build this competency before the school placement.

Four conditions keep this gap open. The program has no assembly laboratory or hands-on assembly course, and its few practice machines are old. With too few machines for one per student, some learners only watch. Slow purchasing leaves the hardware behind what schools and industry use, and slow repair funding shrinks the number of working machines further. Hands-on practice also carries risk: a wrongly inserted CPU can end up with bent pins, as the department has experienced, and electrostatic discharge can ruin circuits, so instructors limit students' contact with real components.

1.2 Gap and Aim

VR can address each of these conditions: a learner can assemble the same current-model computer again and again without damaging it. Higher education uses VR mainly to train procedures and skills where safety or cost restricts real

practice (Jensen & Konradsen, 2018; Radianti, Majchrzak, Fromm, & Wohlgenannt, 2020), and a serious VR game for computer assembly has already been tested with undergraduates (Checa, Miguel-Alonso, & Bustillo, 2023). Three gaps remain. VR tasks and assessment are rarely grounded in the occupational standard that will later certify learners; pre-service teachers, who need this skill during practicum and will later teach it, are seldom studied; and little is known about how teachers who build their own VR materials use generative AI to produce media, although production cost is one of their main obstacles.

This design-and-development study therefore built a Meta Quest 3 VRLE for computer assembly with (a) activities mapped to Thai occupational competency unit ICT-IKTT-098B, Install Computer Systems; (b) controller-free hand tracking; and (c) videos, images, and narration produced with generative AI tools. It contributes a design case in which the performance criteria of an occupational standard became three graded simulation tasks with rule-based feedback, and feasibility evidence from a tryout with Thai pre-service teachers, interpreted within the limits of a one-group design.

2. Research Questions, Objectives, and Hypothesis

RQ1 (design): How can a VRLE for computer assembly be designed and developed so that its tasks align with competency unit ICT-IKTT-098B and its learning media are produced with generative AI? The matching objective was to develop such a VRLE and a supporting learning website.

RQ2 (feasibility and learner outcomes): How do experts rate the VRLE, and how do learners perform and respond after a learning sequence built around it? The matching objective was to examine (a) expert ratings of quality, (b) achievement before and after the sequence, (c) computer assembly competency on real hardware at the end of the sequence, and (d) learner satisfaction.

H1 (for RQ2b): Posttest achievement scores will be higher than pretest scores. The direction of H1 was set before data collection, but the study was not preregistered.

Apart from H1, no success criteria were fixed in advance; the rating bands in Section 4.4 are used only for description, and all results are interpreted as evidence of feasibility, not of effectiveness.

3. Literature Review

3.1 Immersive VR for Procedural Hardware Skills

Compared with 3D media on a desktop screen, VR viewed through a head-mounted display (HMD) gives learners a sense of being inside the space and lets them manipulate objects physically. In a meta-analysis, HMD-based VR generally outperformed less immersive conditions, although effects varied by domain (Wu, Yu, & Gu, 2020), and in professional training, gains were clearest for procedural and spatial tasks such as assembly and maintenance (Renganayagalu, Mallam, & Nazir, 2021).

Findings are not uniformly positive. When immersion adds cognitive load, presence may rise while learning does not (Makransky & Petersen, 2021); VR studies tend to be short and small and rarely test transfer to real tasks (Hamilton, McKechnie, Edgerton, & Wilson, 2021); and the fit between a simulation and its training objective appears to matter more than the hardware (Renganayagalu et al., 2021). The nearest precedent, Checa et al. (2023), compared a controller-based VR serious game for computer assembly with desktop and webcam-lecture conditions in 77 first-year undergraduates; VR helped with visual knowledge and with linking concepts but added little to theoretical knowledge.

Thai evidence comes mainly from nursing education, where VR preparation was associated with practical skills, self-confidence, and attitudes (Nuilers, Chiewsothorn, & Injui, 2022; Oatme, Changkaew, Kruachottikull, & Tanuparbrungsun, 2024), but the outcomes were mainly self-reported rather than rated by an observer.

3.2 Simulation-Based Learning and Learning Mechanisms in VR

Simulations substantially improve complex skills in higher education, especially when learners receive worked examples, prompts to reflect, and feedback (Chernikova et al., 2020). Activities in this study followed Kolb's (1984) experiential learning cycle: learners try something in the simulation, notice how the system responds, form a rule, and then apply it to real hardware.

Models of simulation-based learning name their phases differently but overlap (Table 1; Groom, Henderson, & Sittner, 2014; Jeffries, 2005; Joyce, Weil, & Calhoun, 2015; Lateef, 2010). The check marks in Table 1 record the researcher's own reading of whether each source names or describes a step. Most of the sources come from healthcare simulation, but their steps describe how a simulated practice session is organized rather than nursing content, so they apply equally to practice on computer hardware. The researcher derived five steps: prebriefing, scenario, problem solving, debriefing, and evaluation. Prebriefing appears in only two sources but was retained because the INACSL standard (Watts et al., 2021) requires it and each VR room needed an introduction.

Table 1. Synthesis of Simulation-Based Learning Steps in Prior Models and the Steps Adopted in This Study

Step	Joyce et al. (2015)	Jeffries (2005); Groom et al. (2014)	Lateef (2010)	Watts et al. (2021)	Kolb (1984), learning theory	This study
Prebriefing	✓	–	–	✓	–	✓
Scenario	✓	✓	✓	✓	✓	✓
Problem solving	✓	✓	–	–	✓	✓
Debriefing	✓	✓	✓	✓	✓	✓
Evaluation	–	✓	✓	✓	–	✓

Note. ✓ = step included in the model; – = step not included. Kolb (1984) is a learning theory rather than a simulation model and is included as the theoretical rationale for the sequence.

CAMIL, the Cognitive Affective Model of Immersive Learning, holds that presence and agency influence learning through interest, motivation, and cognitive load (Makransky & Petersen, 2021). Seating a part by hand gives learners agency directly, and because hand tracking spares them from memorizing controller buttons, it should lower task-irrelevant load (Sweller, van Merriënboer, & Paas, 2019).

3.3 Generative AI in Instructional Media Production

University case studies show that teaching staff mostly use generative AI to produce materials, tests, and feedback, but the output still needs human checking (Belkina et al., 2025). AI-generated instructional videos improved vocabulary recall but lowered social presence (Xu et al., 2025), and AI-generated voices and avatars increased engagement and reduced extraneous cognitive load (Zhang, Lucas, Bem-haja, & Pedro, 2025). Work combining AI with VR has centered on conversational agents: Hemminki-Reijonen, Hassan, Huotilainen, Koivisto, and Cowley (2025) warned that AI characters are less reliable than traditional sources of factual information, and a Thai 360-degree VR tour with conversational AI raised high school students' intention to study computer science more than their behavioral commitment (Lertbumroongchai, Janratchakool, & Nittayathammakul, 2025). In this study, generative AI was used only to produce media; the headset gives rule-based feedback, and no AI model runs while the VRLE is in use.

3.4 Occupational Competency Standards

TPQI, the Thailand Professional Qualification Institute, drafts occupational standards with employers and professional associations and certifies individuals against them (Thailand Professional Qualification Institute [TPQI], n.d.). For the occupation Computer and Computer System Service Provider, Level 3, unit ICT-IKTT-098B, Install Computer Systems, has three elements: 30401.01, plan and prepare for installation; 30401.02, install computer systems and devices; and 30401.03, test system operation. Element 30401.02 underlies both the VRLE tasks and the skills assessment.

3.5 Conceptual Framework

In the conceptual framework (Figure 1), four design elements (a hand-tracked 3D virtual environment, simulation-based learning, TPQI element 30401.02, and generative AI-assisted media production) rest on CAMIL, Kolb's cycle, and cognitive load theory and are expected to shape learning achievement, competency on real hardware, and learner satisfaction.

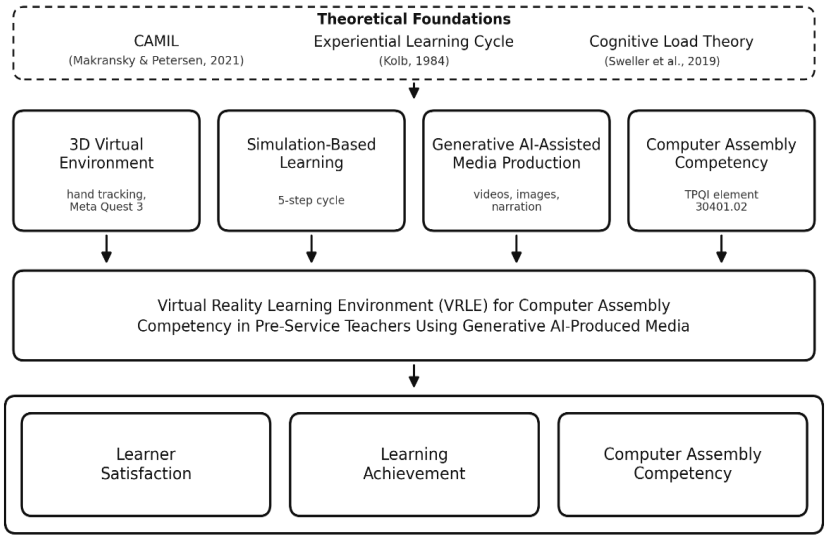


Figure 1. Conceptual Framework of the Study

4. Methodology

4.1 Research Design

The study followed a design-and-development (R&D) approach. The VRLE was developed with the ADDIE model (Tiantong, 2005) and then examined in a feasibility tryout with a one-group pretest–posttest design. No control group was formed, because every student taking the pre-practicum training was meant to be prepared in the same way before the school placement. Section 6.5 returns to the limitations of this decision.

4.2 Participants

The population was the 54 second-year students of the Computer Technology program in a computer education department at a public technological university in Bangkok, Thailand, enrolled in either a four-year track (practicum in Year 4) or a three-year credit-transfer track for holders of the Higher Vocational Certificate (practicum in Year 3). In Semester 2 of academic year 2025, the department offered a voluntary computer assembly training project, and 36 students (66.7%; four-year track, n = 23; three-year track, n = 13) enrolled and gave written consent, including consent for photographs. All had used VR in a required course on building VR instructional media, and none had yet started the practicum. Because attendance and responses varied, 35 learners completed both achievement tests under their names, 36 were rated for competency, and 28 returned the anonymous satisfaction questionnaire.

Three content experts and three technical experts, all holding a doctorate in computer education and selected purposively for expertise in instructional media innovation, VR, or computer assembly, rated the VRLE. The content experts also checked the accuracy of the AI-generated media during development, so their content ratings are not fully independent of that checking.

4.3 Development of the VRLE

4.3.1 Analysis

The analysis covered content, learners, and technology. From unit ICT-IKTT-098B, the researcher derived three topics: computer components, installation and assembly, and troubleshooting. The mentor interviews (Section 1.1) showed that most learners had handled few real components, so they needed a medium in which errors cost nothing, current hardware could be simulated, and attention could be held. The Meta Quest 3 was selected because its display is sharp enough to read the fine print on circuit boards and it tracks bare hands without controllers.

4.3.2 Design

Instruction was organized around a three-phase learning process model (Figure 2).

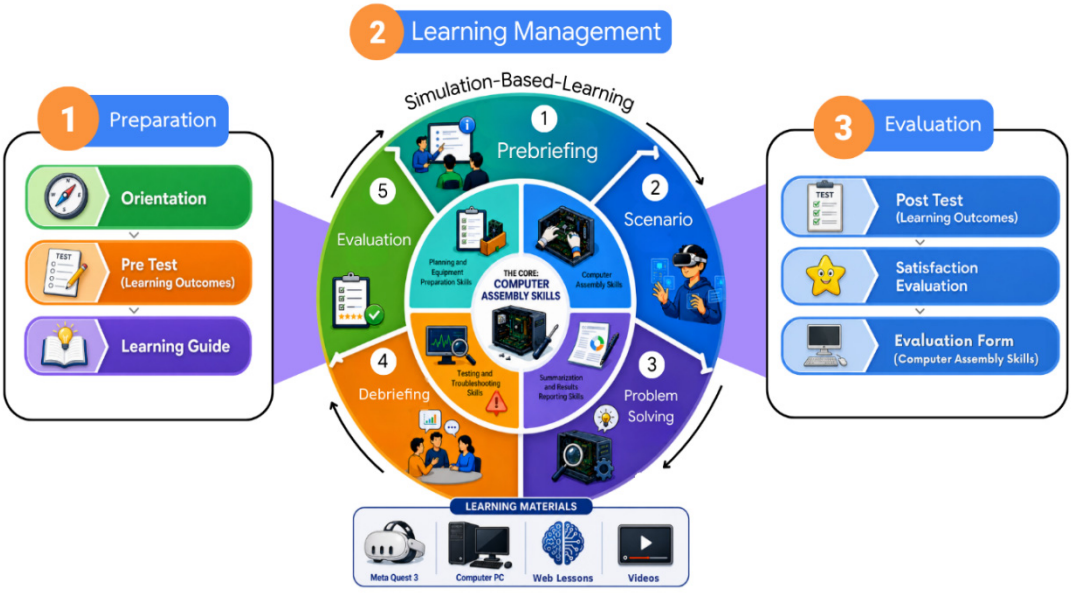


Figure 2. Learning Process Model (diagram created by the researcher in Canva; some illustrations were generated with ChatGPT)

Phase 1: Preparation. The instructor introduced the activities and their sequence, learners took the 10-item achievement pretest on the learning website, and the instructor then introduced the VR media and showed how to operate them with bare hands.

Phase 2: Learning management. Learners followed the five-step cycle synthesized in Table 1: (1) prebriefing, in which each VR room opened with an introductory video and a palm scan started the activity; (2) scenario, in which learners worked through three VR rooms of increasing difficulty (Table 2); (3) problem solving, in which learners built a computer on real hardware, fixed faults in machines prepared for this step, and recorded their results; (4) debriefing, in which the class reviewed what each learner had done, why each action was right or wrong, and how it related to real work; and (5) evaluation, in which learners confirmed that their computers ran normally while the instructor assessed the work.

Phase 3: Evaluation. Learners took the achievement posttest and the satisfaction questionnaire, and their competency was assessed with the computer assembly competency form. Table 2 maps each VR room to the competency unit, its activities, and its feedback.

Table 2. Alignment of VRLE Rooms With Target Competencies, Activities, and Feedback

Room	Target competency	Main activities	Feedback
1. Getting to know components	Identify components and describe their functions and properties	Handle 3D components; palm-scan information boards to play videos; answer a five-item Mini Quiz by placing parts in answer slots	Green slot if correct; red if wrong, with the count reset to 0/5
2. Assembly sequence	Install computer systems and devices in the correct order (30401.02)	Assemble one computer in sequence, guided by step labels and a demonstration video	Ghost images show snap points; a state machine reports progress and order errors
3. Troubleshooting	Analyze and replace faulty components (30401.02.03)	As a technician's assistant, replace RAM, CPU, and mainboard in increasing difficulty, using a red tray for faulty parts and a blue tray for parts to reinstall	Hints on parts to reinstall; on-screen list of remaining faults

Note. Codes refer to elements and performance criteria of TPQI competency unit ICT-IKTT-098B.

4.3.3 Development

In Blender, the researcher modeled each component at real-world scale with physically based rendering (PBR) materials and exported the models as FBX files; a few models came from BlenderKit under its Royalty Free or CC0 licenses. The scenes were built in Unreal Engine 5.6.1 with Lumen lighting, Nanite geometry, and Chaos Physics. Interaction logic, scripted in Blueprints Visual Scripting with the Meta XR plugin, covered (a) grasping, by pinching small parts or closing the hand around large ones; (b) snapping, which tests a part's distance and angle from its socket; (c) a state machine in Room 2 that checks assembly order; and (d) the fault scenarios in Room 3. Feedback was visual (green and red highlights) and auditory (spoken hints, fan noise, and a click when RAM locks in place). Figure 3 shows both tools, and Figures 4 to 6 show the three rooms.



Figure 3. Development Environment: (a) Scene and Interaction Development for Room 3 in Unreal Engine 5.6.1 and (b) 3D Modeling of a Computer Case in Blender

Room 1 (Figure 4) is a learning hall in which a palm scan at each component's information board plays a short video and learners can lift and rotate the part; passing a five-item Mini Quiz opens the next room.



Figure 4. Room 1: Component Information Boards in a Virtual Learning Hall (some in-scene videos and illustrations were generated with AI; see Table 3)

In Room 2 (Figure 5), learners assemble one computer, guided by a non-player character (NPC), step labels, and a demonstration video; ghost images mark the snap points, a state machine catches steps done out of order, and a dashboard checks off each completed step.



Figure 5. Room 2: Assembling Components in Sequence With Hand Tracking (some in-scene videos and illustrations were generated with AI; see Table 3)

In Room 3 (Figure 6), learners act as computer technicians and must correctly replace the defective parts in three faulty computers, ordered from simple to difficult.



Figure 6. Room 3: Replacing Faulty Parts Using Red and Blue Trays (some in-scene videos and illustrations were generated with AI; see Table 3)

AI-generated videos appear in every VR room to strengthen immersion. Table 3 lists the tools, versions, and plans for each production step (the ElevenLabs free plan requires the credit given there and restricts use to non-commercial purposes), and Figure 7 shows the main steps. One video clip took about two to three hours to produce, and each generation session usually needed one or two regenerations because of hallucinated content; for example, objects in a generated video drifted away from the source image and no longer matched the prompt. The researcher then revised the prompt and regenerated the output, and the content experts verified the final versions; the narration contained no content errors. In the researcher's estimate, comparable videos made without generative AI would have taken considerably longer. The AI component was not evaluated separately: production time was not compared with a non-AI workflow, and learners' perceptions of the AI-generated media were not measured.

Table 3. Generative AI Tools Used to Produce the Learning Media

Step	Tool, version, and plan	Output	Checks and notes
Scripts and storyboards	ChatGPT; Gemini	Dialogue scripts and storyboards for each room	Edited by the researcher before production
Illustrations	Gemini; Google Flow (Google AI Pro)	Scene images and illustrations	Regenerated when content was wrong
Video clips	Google Flow with Veo 3.1 (Google AI Pro, one month, THB 750)	Instructional video clips shown in the VR rooms	About 2–3 hours per clip; usually 1–2 regenerations per session; verified by content experts
Narration	ElevenLabs (free plan; credited as elevenlabs.io)	Thai narration	No content errors found
Code and website drafts	Gemini	System plan, draft Blueprint logic, learning website	Tested and corrected by the researcher

Note. Generative AI was used only to produce learning media and draft materials; no AI model runs while learners use the VRLE.

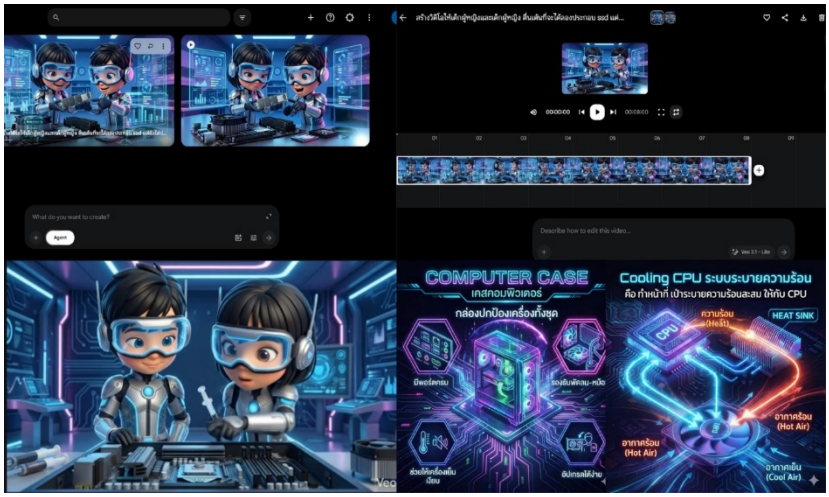


Figure 7. Producing VR Learning Media With Generative AI in Google Flow With Veo 3.1 (all scenes shown were generated with AI)

A learning website on Google Sites (https://kmutnb.link/simspace-pc-lab), also built by the researcher, holds the theory lessons, a browser game called PC Workshop, both achievement tests, the VR application and its manual, and the evaluation forms.

4.3.4 Implementation and Evaluation

Before the tryout, the researcher confirmed that the system ran stably on Windows 11 and Meta Quest 3 and tuned hand-tracking distances to users' body proportions; the experts evaluated the VRLE in early March 2026, before learners used it.

4.4 Instruments

The five instruments are summarized in Table 4.

Table 4. Research Instruments

Instrument	Structure	Scale	Quality evidence
Content quality form	13 items in 3 domains (content accuracy, procedures, instructional design)	5-point rating	Completed by 3 content experts
Technical quality form	14 items in 3 domains (graphics and scenes, interaction and usability, technical performance)	5-point rating	Completed by 3 technical experts
Achievement test	10 multiple-choice items drawn at random from a 20-item pool for each learner at each test	1 = correct, 0 = incorrect (maximum 10)	IOC 0.67–1.00 (20-item pool, 3 experts); reliability not estimable because item responses were not stored
Competency assessment	4 criteria based on ICT-IKTT-098B	5-point rating	IOC = 1.00 for all criteria
Satisfaction questionnaire	15 items in 3 domains	5-point rating	Cronbach's α = .91 (domains .76–.86), *n* = 28

Note. IOC = index of item–objective congruence (Rovinelli & Hambleton, 1977). For each learner and each test, the testing system drew 10 items at random from the 20 items that met the IOC criterion.

The achievement test covered nine objectives, and Table 5 links the item pool to the objectives and to the part of the sequence where each was taught. Working safely, installation precautions, maintenance, and protection against electrostatic discharge (ESD) were taught in the website lessons and the real-hardware session rather than in the VR rooms, so the test measures the whole learning sequence. Because the testing system stored only total scores, test reliability (e.g., KR-20), item difficulty, and item discrimination could not be estimated. Competency was assessed on four criteria: (1) plan and prepare components, (2) install and assemble components, (3) test the system and solve problems, and (4) summarize and report the results. A single rater, the researcher, who had developed the VRLE and taught the course, scored each learner while assembling a real computer. Because this followed the real-hardware problem-solving step, the ratings describe performance at the end of the whole sequence and do not isolate transfer from VR; no pre-instruction rating was made, and no TPQI pass standard was applied. Each criterion was rated on five levels (5 = excellent, 4 = very good, 3 = good, 2 = fair, 1 = needs improvement). For planning and preparation, a 5 meant completing all five sub-tasks, including preparing the workspace, checking component compatibility, and protecting against ESD; a 3 meant correct tools and hardware but a neglected workspace or static protection; and a 1 meant no preparation. Such written descriptors were prepared only for this criterion; the other three were rated with the level labels alone, which limits the transparency of those ratings. Criteria 1 and 4 were practiced in the website lessons and the real-hardware session, where learners recorded their results, rather than in the VR rooms.

Table 5. Blueprint of the Achievement Test Item Pool

Objective	Pool items (IOC)	Taught in	Practiced in VR
1. Identify components	1–2 (0.67)	Website lessons; Room 1	Yes
2. Explain functions	3–4 (0.67)	Website lessons; Room 1 videos	Yes
3. Describe specifications	5–7 (1.00)	Website lessons; Room 1 information boards	Yes
4. Explain the assembly order	8–11 (1.00)	Website lessons; Room 2; real hardware	Yes
5. Diagnose basic faults	12–13 (1.00); 14 (0.67)	Website lessons; Room 3; real hardware	Partly
6. Replace defective parts	15–16 (1.00)	Room 3; real hardware	Yes
7. Work safely	17–18 (1.00)	Website lessons; real hardware	No
8. Observe installation precautions	19 (1.00)	Website lessons; real hardware	No
9. Carry out maintenance	20 (1.00)	Website lessons	No

Note. IOC values come from three experts. Each test drew 10 items at random from this pool, so the objectives covered differed between learners and between the pretest and posttest.

Mean ratings were interpreted with the equal-interval bands of Pimentel (2010): 4.21–5.00, very good; 3.41–4.20, good; 2.61–3.40, moderate; 1.81–2.60, fair; and 1.00–1.80, needs improvement. The bands are descriptive only and were not

set as success criteria; because they can mask disagreement, item-level patterns and individual experts' means are also reported.

4.5 Data Collection

The tryout took place in the department's laboratory in Semester 2 of academic year 2025, and the full sequence took about three hours. Learners were divided into a morning and an afternoon session so that no more than 20 learners used the 20 Meta Quest 3 headsets at one time, each keeping a headset throughout. Each VR session lasted roughly 15–20 minutes, and learners could re-enter any room when unsure; the VRLE did not log room time, attempts, or errors, so individual VR exposure was not recorded. Learners moved through the three phases in order (Figures 2 and 8) and completed the posttest and questionnaire online.



Figure 8. Pre-Service Teachers Practicing in the VRLE and Assembling Real Computers During the Tryout

4.6 Data Analysis

Ratings were summarized as means and standard deviations. For each expert panel, the report gives domain means, each expert's domain mean, the range of item means, and the within-group agreement index $r_{wg(j)}$ (James, Demaree, & Wolf, 1984); overall panel means are item-weighted. Pretest and posttest records were matched by learner name; for one learner who submitted the pretest twice, the first attempt was used, and one learner without a pretest was excluded, leaving 35 pairs. Because the difference scores were bounded, heavily tied, and not normally distributed, a one-tailed Wilcoxon signed-rank test was the primary test, with zero differences excluded as in Wilcoxon's (1945) original procedure, tied ranks corrected in the variance, and the normal approximation used without continuity correction. The effect size $r = z/\sqrt{n}$ is reported for the non-zero pairs and for all 35 pairs, with a 95% bootstrap confidence interval (10,000 resamples). As a secondary analysis, a one-tailed paired-samples t test with Cohen's d_z (Lakens, 2013) and the 95% confidence interval of the mean difference was run, and it was repeated without one outlying case. One-tailed tests were used because H1 was directional. The class-average normalized gain, g = (post − pre)/(10 − pre) (Hake, 1998), is reported descriptively. Analyses were run in jamovi (The jamovi project, 2026) and checked in Python with SciPy (Virtanen et al., 2020).

5. Results

5.1 The Developed VRLE (RQ1)

Development produced a Meta Quest 3 VRLE with a start menu, three rooms (Table 2; Figures 4 to 6), and a supporting learning website. Learners move on only after passing the assessment that closes each room: an error-free run through the five Mini Quiz items in Room 1, a finished build in Room 2, and three repair scenarios in Room 3. As partial evidence of alignment, the content experts rated the fit between the content and the occupational qualification at M = 4.67; no separate task-by-criterion alignment assessment was carried out.

5.2 Expert Evaluation (RQ2a)

As Table 6 shows, both panels rated overall quality very good (content M = 4.74; technical M = 4.45), with instructional design the highest content domain (M = 4.83). Interaction and usability had the lowest mean and the widest spread (M =

4.11; experts' means 3.17, 4.33, and 4.83): one technical expert rated snapping, object physics, visual and audio feedback, and hand-tracking accuracy 3, so these items averaged 4.00 to 4.33. The two lowest content items (M = 4.33) were the inclusion of safety knowledge such as protection against ESD and the accuracy of the troubleshooting guidance, and the content experts recommended adding further safety precautions. Freedom from motion sickness averaged 4.67 because one expert rated it 4. Agreement within the panels was high, $r_{wg(j)}$ = .99 for content and .97 for technical quality.

Table 6. Expert Ratings of VRLE Quality

Domain	*Mean*	Experts' means	Item mean range	Level
Content experts (n = 3)				
Content accuracy	4.75	4.75, 5.00, 4.50	4.67–5.00	Very good
Procedures and practice steps	4.67	4.40, 5.00, 4.60	4.33–5.00	Very good
Instructional design	4.83	5.00, 5.00, 4.50	4.67–5.00	Very good
Content overall	4.74	4.69, 5.00, 4.54	4.33–5.00	Very good
Technical experts (n = 3)				
Graphics and scene design	4.67	4.40, 4.60, 5.00	4.33–5.00	Very good
Interaction and usability	4.11	3.17, 4.33, 4.83	4.00–4.33	Good
Technical performance	4.78	5.00, 4.67, 4.67	4.67–5.00	Very good
Technical overall	4.45	4.00, 4.50, 4.86	4.00–5.00	Very good

Note. Ratings on a 5-point scale. Experts' means are each expert's mean for the domain. Overall values are item-weighted means across all items of a panel.

5.3 Achievement (RQ2b)

Among the 35 learners with matched tests, the posttest mean (M = 9.09, SD = 0.82) was 0.89 points above the pretest mean (M = 8.20, SD = 1.49), 95% CI [0.27, 1.50] (Table 7). Scores rose for 17 learners, stayed the same for 12, and fell for 6. The difference scores were not normally distributed (Shapiro–Wilk W = 0.84, p < .001). The Wilcoxon signed-rank test showed a significant increase (23 non-zero pairs, W+ = 233.5, z = 2.95, p = .002, one-tailed), which supports H1, with r = .62 for the non-zero pairs and r = .50 for all 35 pairs, 95% bootstrap CI [.24, .68]. The paired-samples t test agreed, t(34) = 2.92, p = .003 (one-tailed), with a moderate effect size (Cohen's d_z = 0.49).

Table 7. Pretest and Posttest Achievement Scores (n = 35)

Test	*Mean*	*SD*	Mean difference [95% CI]	*t*(34)	*p*	d_z
Pretest	8.20	1.49	0.89 [0.27, 1.50]	2.92	.003	0.49
Posttest	9.09	0.82				

Note. Maximum score = 10. Records were matched by learner name. Wilcoxon signed-rank test (primary): z = 2.95, p = .002, r = .50. The p values are one-tailed; the 95% CI of the mean difference is two-tailed.

Two features of the data bear on interpretation. First, there was a ceiling effect: 13 learners (37.1%) scored the maximum of 10 on the posttest, and five already had the maximum on the pretest, three of whom scored lower on the posttest. The class-average normalized gain, reported descriptively, was g = 0.49. Second, one learner's score rose from 2 to 10; without this case, the difference remained significant, t(33) = 2.99, p = .003, d_z = 0.51.

5.4 Computer Assembly Competency (RQ2c)

At the end of the sequence, overall competency on real hardware was rated very good (M = 4.85, SD = 0.22; Table 8); these descriptive ratings also reflect the real-hardware practice that preceded them. All learners received full marks for planning and preparing components, so this criterion did not distinguish between learners, and testing the system and solving problems had the lowest mean (M = 4.75, SD = 0.44). Twenty-one learners (58.3%) were rated at the maximum on all four criteria. Because no rating was made before instruction, these values cannot be read as a gain.

Table 8. Computer Assembly Competency Ratings (n = 36)

Criterion	*Mean*	*SD*	Level
1. Plan and prepare components	5.00	0.00	Very good
2. Install and assemble components	4.83	0.38	Very good
3. Test the system and solve problems	4.75	0.44	Very good
4. Summarize and report results	4.81	0.40	Very good
Overall	4.85	0.22	Very good

Note. Overall values are computed from each learner's mean across the four criteria.

5.5 Satisfaction (RQ2d)

Twenty-eight of the 36 learners (77.8%) returned the anonymous satisfaction questionnaire. Satisfaction was very good in every domain (Table 9), with an overall mean of 4.79 (SD = 0.31). The highest-rated items (both M = 4.86) were that VR showed a computer's structure more clearly than textbook pictures and that replacing faulty parts helped learners practice analytical thinking; the lowest were wanting other courses to adopt VR (M = 4.68) and the ease and enjoyment of controlling the VRLE with bare hands (M = 4.71). Of the 420 responses, 80.7% were the highest option and 98.1% were 4 or 5.

Table 9. Learner Satisfaction With the VRLE (n = 28)

Domain	Items	*Mean*	*SD*	Level
Content and learning	5	4.82	0.29	Very good
Usability and facilities	4	4.76	0.35	Very good
Attitudes and perceived benefits	6	4.77	0.40	Very good
Overall	15	4.79	0.31	Very good

Note. Domain and overall values are computed from each learner's mean rating across the items in that domain.

6. Discussion

6.1 Quality of the VRLE and the Weak Point in Interaction

All content domains were rated very good, with instructional design highest (M = 4.83). One possible reason, which the data cannot confirm, is that each room was planned from what competency element 30401.02 expects a technician to do rather than from what the engine or headset can display, the outcomes-first approach that Radianti et al. (2020) recommend for VR in universities.

The interaction results are more informative. This domain had the lowest mean (M = 4.11) and the least agreement (experts' means 3.17 to 4.83), and the items on snapping, physics, and feedback, on which every grasp depends, averaged only 4.00 to 4.33. If a pinch fails or a RAM module will not seat, attention may shift from the hardware to the controls. Cognitive load theory (Sweller et al., 2019) and CAMIL (Makransky & Petersen, 2021) offer a possible explanation, namely that failed interactions add extraneous load and weaken agency, but presence, agency, and cognitive load were not measured, so this explanation remains untested. Buckingham (2021) likewise notes that bare-hand tracking is less precise and less comfortable than a handheld controller. One technical expert rated freedom from motion sickness 4, and the researcher informally observed motion sickness in some learners who were not yet used to the headset; without a cybersickness scale, how often it occurred is unknown. A next version should loosen snapping tolerances, let learners switch to a controller, and log failed grasps, attempts, and time per room.

6.2 Achievement and Competency

Achievement rose with a moderate effect, although six learners scored lower on the posttest. The components of the sequence cannot be disentangled: by the time of the posttest, learners had used the website, practiced in VR, built and repaired real computers, and joined a debriefing. Clark (1994) argued that learning stems from the instructional method a medium carries rather than from the medium itself, a distinction this design could not make, and Bakim, Abdul Hanid, Zakaria, and Syed Azman (2026) likewise reported gains when an augmented reality application was embedded in 5E inquiry teaching. Scores therefore rose over a learning sequence built around the VRLE, not necessarily because of VR. For the same reason, the role of VR as rehearsal before real hardware was not tested, because no condition lacked either step. The d_z of 0.49 is also a within-group effect and cannot be compared directly with between-group meta-analytic estimates (Wu et al., 2020). Isolating the VR component requires comparison conditions and a delayed test: Shen, Chen, Raffe, and Leong (2021) found that a video tutorial matched high-immersion VR on an immediate assembly test, but two weeks later only learners who had trained in VR maintained their skill level.

The 10-item test also had too low a ceiling for this group: the pretest mean was already 8.20, five learners had full marks before instruction, and 13 had full marks afterward. The drop in the standard deviation from 1.49 to 0.82 and the lower posttest scores of three learners who began at the maximum may reflect this ceiling, differences between the randomly drawn forms, and measurement error as much as learning.

All competency criteria were rated very good. Every learner received the top rating for planning and preparation, but this criterion was practiced in the website lessons and the real-hardware session rather than in the VR rooms, and with no variance it does not distinguish between learners. Testing and problem solving came last: Room 3 offers only three scenarios and names the faulty part in each, so learners did not practice reasoning from a symptom, such as a BIOS beep code, to its cause, although diagnostic skills develop from varied cases with explanatory feedback (Chernikova et al., 2020). With so many ratings at 5, the scale probably had a ceiling, and with the unblinded developer as the only rater, the scores may lean upward.

6.3 Satisfaction

Satisfaction was high in every domain. The item "I felt relaxed and did not worry about breaking equipment while practicing" averaged 4.82, consistent with the safe space for mistakes that simulation is intended to offer (Lateef, 2010), which matters where students fear damaging scarce hardware. These ratings nevertheless need careful reading. Most responses were at the top of the scale; the learners already knew VR, and each room opened with a guided introduction of the kind that reduces the novelty effect (Miguel-Alonso, Checa, Guillen-Sanz, & Bustillo, 2024), but the VRLE itself was new to them; and ratings collected by the developer, who was also their instructor, are open to social desirability bias (Hamilton et al., 2021).

6.4 Theoretical and Practical Implications

Theoretically, the findings fit CAMIL's view that agency supports learning in VR and hint at the reverse, because the lowest expert domain (interaction and usability, $M = 4.11$) and one of the two lowest learner items (bare-hand control, $M = 4.71$) both concern hand tracking. As presence, agency, usability, and cognitive load were not measured, this reading is tentative. Future work on hand-tracked VR should use validated instruments, such as the System Usability Scale, a cybersickness questionnaire, and a cognitive load measure, together with system logs.

Practically, the sequence offers technical teacher education a model that can be tried and tested: rehearsal in VR comes first and work on real computers with the instructor follows, so that VR prepares learners for hardware rather than replacing it; whether this order improves later work on real hardware remains to be tested. Teachers who produce media with generative AI should also treat accuracy checking as a formal step, because a well-made video that shows a hardware procedure incorrectly will teach that error.

6.5 Limitations

Several limitations apply. First, without a control group, testing effects, learning during the real-hardware session, and maturation remain possible explanations, so the study cannot show that the VRLE caused the gains. Second, the achievement test was short (10 items) and showed a ceiling effect; its randomly drawn forms were not equated between learners or between the pretest and posttest, and its reliability and item statistics are unknown because only total scores were stored. Third, the satisfaction questionnaire reached a ceiling, with 14 of 28 respondents choosing the highest option for every item, which may have inflated Cronbach's α, and eight learners did not return it. Fourth, each expert panel had only three members, so a single rating could shift a domain mean considerably. Fifth, competency was rated once, after the real-hardware practice, by the researcher, who also developed the VRLE and taught the course; only one of the four criteria had written level descriptors, the rater was not blinded, and there was no second rater or baseline rating. Sixth, the VRLE recorded no system logs or individual time in VR, and presence, cognitive load, usability, and cybersickness were not measured. Seventh, the generative AI component was described but not evaluated. Eighth, the study was not reviewed by an ethics committee, and the researcher's role as the learners' instructor may have affected voluntariness and the ratings. Finally, as volunteers from one institution, the participants may have been more motivated than the 18 students who did not enroll, and because data were collected straight after instruction, retention and transfer to the teaching practicum were not tested.

7. Conclusion

This study developed a Meta Quest 3 VRLE for computer assembly whose three rooms follow competency unit ICT-IKTT-098B, whose hand tracking lets learners handle parts directly, and whose videos, images, and narration were produced with generative AI and verified by the researcher and the experts. Experts rated it very good overall but identified interaction ($M = 4.11$) as the part most in need of work, and in the tryout, achievement rose significantly with a moderate effect, alongside very high competency and satisfaction ratings.

These findings show that the VRLE is feasible and well received as part of a learning sequence that ends with real equipment, particularly in departments short of hardware, but they cannot establish that the VRLE or VR rehearsal caused the gains. The next step is a quasi-experimental comparison with a desktop or video condition, using a parallel or harder test form, a blinded assessor, and a delayed posttest four to six weeks after instruction. Room 3 also needs scenarios in which learners work out the fault from symptoms such as BIOS beep codes. The next version of the VRLE will record completion time, log attempts and errors, send practice data to the instructor, and include built-in help for learners who get stuck.

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Author contributions

Puttida Sakulviriyakitkul is the sole author and was responsible for conceptualization, methodology, software, investigation, formal analysis, data curation, visualization, and writing (original draft, review and editing).

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