



Contents lists available at [Journal ELORA](#)

JRTI (Jurnal Riset Tindakan Indonesia)

ISSN: 2502-079X (Print) ISSN: 2503-1619 (Electronic)

Journal homepage: <https://jrti.eloracenter.org/jrti>



Isometric virtual laboratory design and validation: a multimedia learning approach to android-based UTP cabling instruction

Deni Sartika, Rizky Ema Wulansari^{*)}, Yeka Hendriyani, Elfi Tasrif

Faculty of Engineering, Universitas Negeri Padang, Padang, Indonesia

Article Info

Article history:

Received Aug 14th, 2026

Revised Sept 11th, 2026

Accepted Oct 02nd, 2026

Keyword:

Virtual laboratory,
Vocational education,
Computer networking,
UTP cabling,
Mobile learning,
4-D model

ABSTRACT

Indonesian vocational high school (*Sekolah Menengah Kejuruan*, SMK) students must master unshielded twisted pair (UTP) cabling, yet pin order, cable types, and connector logic are difficult to visualize, practice time is short, and equipment is often scarce. Grounded in the cognitive theory of multimedia learning and cognitive load theory, this study designed an Android-based virtual laboratory that uses isometric (pseudo-3D) visualization to make the cabling workbench visible on ordinary smartphones. The study addresses a gap in mobile and simulation-based vocational learning research, which has focused on logical network configuration in higher education and has rarely addressed physical cabling at the secondary level. It examined the product's validity, practicality, and preliminary effectiveness as a supplementary medium for UTP cabling concepts. Development followed the 4-D model (define, design, develop, disseminate). Three media and three material experts evaluated the prototype using Aiken's V, and three practitioners and 16 Grade 10 Software and Game Development (PPLG) students rated its practicality. Effectiveness was examined in a pilot study using a pre-experimental one-group pretest-posttest design over eight sessions with a 24-item conceptual test (KR-20 = 0.94). The sample was the entire Grade 10 PPLG class (total sampling); an a priori power analysis showed that 15 participants were needed to detect a large paired effect ($d_z = 0.80$, $\alpha = .05$, power = .80). Media and material validity were 0.84 and 0.91. Practicality averaged 88.00% (practitioners) and 85.25% (students). Mean scores rose from 62.50 ($SD = 12.73$) to 85.68 ($SD = 8.47$), $t(15) = 8.14$, $p < .001$, $d_z = 2.04$, $(g) = 0.62$, and 93.75% of students reached the mastery level. Because no control group was used, this gain indicates an association with the intervention rather than a causal effect, and it may also reflect regular instruction, testing, and maturation. The isometric virtual laboratory is a valid and practical supplementary medium for resource-limited workshops, and controlled studies are needed to establish its effectiveness.



© 2026The Authors.

This is an open access article under the CC BY-NC-SA license
(<https://creativecommons.org/licenses/by-nc-sa/4.0>)

Corresponding Author:

Rizky Ema Wulansari,
Faculty of Engineering, Universitas Negeri Padang
Email: rizkyema@ft.unp.ac.id

Introduction

Vocational education and training (VET), if effective, is meant to get students out into the labor market with skills that match what is required in highly digitalized workplaces. This can only be done effectively if there is not only a good curriculum but also availability of digital tools and pedagogical skills in vocational schools (Cattaneo et al., 2022; Roll & Ifenthaler, 2021). In Indonesia, it seems that as vocational high school (SMK) student populations have grown so have the concerns raised by critics with regard to the mismatch between the

theoretical content of courses and the kind of practical skills that industry demands (Suharno et al., 2020). Labor-market data reflect this concern: in February 2025, SMK graduates had the highest open unemployment rate of all education levels (8.00%), compared with a national rate of 4.76% (Badan Pusat Statistik, 2025). Ideally (*das sollen*), SMK graduates should be able to apply the competencies in their curriculum to authentic workplace tasks; in practice (*das sein*), many SMKs still teach practical content through lectures and slides because equipment and workshop time are limited. So it's not just a matter of introducing SMK staff to new technologies. Rather, it is how these technologies are employed to better align theory-based subjects with hands-on practice.

Computer networking is one area where this association is weak. Networking involves several elements and processes which are not visually or physically available to students, for example, signal paths, device roles, and protocol behavior. Higher education literature indicates that integrating lectures with laboratory or workshop sessions on actual or simulated devices helps students to better understand and learn the subjects (Abdrabou & Shakhathreh, 2021). In the Indonesian curriculum, basic computer network technology concepts are included in the Software and Videogame Development program called (PPLG). Grade 10 students who are part of this program must compare various topologies with each other and they will be assessed on their ability to put together and fix up simple UTP cabling. Even though PPLG is a software-oriented program, the students still need to have a good basic understanding of infrastructure as well.

UTP cabling at a glance looks very simple yet is conceptually heavy with abstract demands. Students need not only to have basic knowledge but also the understanding why the sequence of eight wires for T568A and T568B matters, when a straight-through/crossover cable is to be used, and how a wrong pin layout results in no connection. If teaching is mainly slide-based, students are more inclined to rote learning of procedures that they don't grasp the principles behind. Limiting lab supplies, small amounts of lab time, and the reality that students can't practice again at home further limit the hands-on experience. In resource-limited regions, similar constraints have led the communities to adopt simulation tools (Mwansa et al., 2024; Shambare & Simuja, 2022).

Virtual labs are also one effective solution to those limitations. They provide an environment where students can experiment using the computer without any risk or cost for materials (de Jong et al., 2013). This study adopts the cognitive theory of multimedia learning (Mayer, 2024) and cognitive load theory (Sweller et al., 2019) as its theoretical lens. Because working memory is limited, instructional representations should minimize extraneous processing and help learners select, organize, and integrate relevant information. Under this lens, a virtual laboratory supports learning not simply because it is digital, but because its visual and interactive design makes hidden relations visible while reducing unnecessary cognitive load. As Mayer (2024) points out, the combination of a well-crafted visual display and an easily understandable verbal explanation leads to a reduced use of working memory and a better development of the overall learning experience. A look at the meta-analyses reveals that such design guidelines as signaling, segmenting, and contiguity lead to an enhancement of knowledge, more especially, for difficult subjects (Noetel et al., 2022). Learning through mobile phone allows students the possibility of taking lessons home and carrying out activities outside of the laboratory at school. There is substantial evidence pointing out that mobile learning leads not only to significant improvement in academic performance but also that science learners' achievements are raised significantly by adopting mobile learning (Dong et al., 2024; Garzón et al., 2025).

Empirical study of virtual labs seems, generally speaking, to have produced positive results. The meta-analysis of engineering education concluded with an overall effect of $g=0.686$, with a higher effect for knowledge acquisition ($g=0.865$) compared to operational skills ($g=0.620$) (Li & Liang, 2024). Santos & Prudente (2022) concluded from their meta-analysis in science education that virtual labs had a medium effect, $g=0.587$. In Indonesian SMKs, the Android-based virtual lab raised levels of cognitive abilities of civil engineering students as opposed to conventional instruction (Niswah et al., 2024). A new idea, to bring the mobile augmented-reality laboratory to electro-pneumatics subjects, was highly praised by subject matter experts (Sukardjo et al., 2023). Augmented reality has likewise been applied to learning about computer network devices (Hamzah et al., 2021). Moreover, use of Android and mobile learning platforms for computer network subjects has been validated as effective, practical, and suitable for vocational schools through the work of Novaliendry et al. (2021, 2023).

This argument is, of course, not fully supported by these studies. In fact, in a meta-analysis of conceptual knowledge acquisition, there was no overall benefit of virtual investigation over physical (Mulwijik & Lazonder, 2023). Moreover, immersive virtual reality significantly increased vocational students' motivation but yielded less objective knowledge than a paper-based instruction method (Thomann et al., 2024). In a stratified meta-analysis, it was revealed that the supposed benefits of virtual reality are diminishing as the studies get less risky, and bias becomes more questionable (Layadi et al., 2026). High levels of immersion that may lead to cognitive overload (Makransky et al., 2019) might explain a part of the limited effectiveness of the virtual learning environments. On top of that, studies about augment-reality and its visualization through 3D have demonstrated

that the increase in knowledge gains can be much smaller (Chang et al., 2022). A systematic review also identified a pattern that many virtual laboratory studies employ two-dimensional vendor software as a sole device and credit improvement to it without linking it with design principles (Reeves & Crippen, 2021).

In the end, this research sheds light on many aspects of network education which are not fully covered. For instance, virtual networking labs had largely been limited to the field of higher education and the aspect of logical configuration through emulators or testbeds (Luse & Rursch, 2021; Mwansa et al., 2024). Moreover, they are silent about the issue of physical cabling skills taught at the very beginning in SMK courses. Furthermore, the meta-analyses indicate an added value of simultaneous physical and virtual experiments that exceeds either alone (Wörner et al., 2022). However, development studies very seldom describe a virtual laboratory as an introductory step for, rather than substitution of, practical skills. In vocational development studies, a quite common pattern appears to be where expert views on feasibility are reported but there is no mention of how well learning outcomes of students actually are; or significant differences are reported, without effect sizes. Consequently, it remains unclear how a lightweight, smartphone-based visualization of physical cabling, designed on explicit multimedia learning principles and positioned as preparation for hands-on practice, performs in secondary vocational education.

In order to overcome such challenges, this work presents an Android-compatible virtual lab environment that employs isometric (pseudo-3D) visualization to depict a networking workbench, tools, and cable parts. The lab platform was specifically designed for UTP cabling concepts as part of the PPLG course. The novelty of this study is that, unlike previous virtual networking laboratories that emulate logical configuration in higher education, it targets physical UTP cabling at the SMK level through an isometric smartphone simulation grounded in multimedia learning principles; this innovation lies in the merging of four components rather than in a single feature. One of them is a lightweight isometric representation that can be run on regular smartphones thereby avoiding the price and cognitive burden of immersive systems. Another is a drag-and-drop simulator of cable assembly with a focus on pin order and cable type. Third is an explicit function as a complementary medium that supports the physical practice by being used before and after. Fourth is a comprehensive 4-D development cycle describing validity, usability by both teachers and students, test items reliability, and initial efficacy of the project indicated by an effect size.

Accordingly, this study aimed to (a) develop an isometric Android-based virtual laboratory for UTP cabling through the 4-D model; (b) determine its validity, as measured by Aiken's *V* from media and material experts; (c) determine its practicality, as measured by practitioner and student questionnaire scores; and (d) measure the change in students' conceptual understanding of UTP cabling, as assessed by a 24-item conceptual test before and after using the product and reported with a paired-samples *t*-test, effect size (*dz*), and normalized gain. Four research questions guided the study: (RQ1) How is the virtual laboratory developed through the 4-D model? (RQ2) To what extent does the product meet media and material validity criteria according to experts? (RQ3) To what extent do practitioners and students rate the product as practical? (RQ4) Do students' conceptual understanding scores increase after learning with the product? For RQ4, we expected posttest scores to be higher than pretest scores. The paper reports a design case of a low-resource virtual laboratory in one SMK and shows how such a tool can serve as a valid and practical supplementary medium in schools with limited materials.

Method

Research Design

The research and development work conducted in the study is following a 4-D model proposed by Thiagarajan et al. (1974) consisting define, design, develop, and disseminate stages. The model has been frequently used for creating learning materials and instructional systems (Usmaldi & Amini, 2022) in vocational education schools. The 4-D model was chosen over alternatives such as ADDIE because its define stage explicitly includes front-end, learner, concept, and task analyses, which suit a curriculum-bound product, and its develop stage builds in expert appraisal and developmental testing, which match the validity and practicality criteria used here. Stages and outputs are shown in Figure 1. Product quality was evaluated using three criteria: validity (expertise decision), practicality (learners' response), and effectiveness (a pre-experimental one-group pretest-posttest design; Shadish et al., 2002; Knapp, 2016). Because the school has only one PPLG class per grade, a concurrent control group was not available, and the effectiveness trial was therefore designed and is reported as a pilot (preliminary) evaluation. As Knapp (2016) notes, this design can document change but cannot rule out rival explanations such as testing, maturation, and history; these threats were handled as described in the Procedure and are reflected in the cautious interpretation of the results.

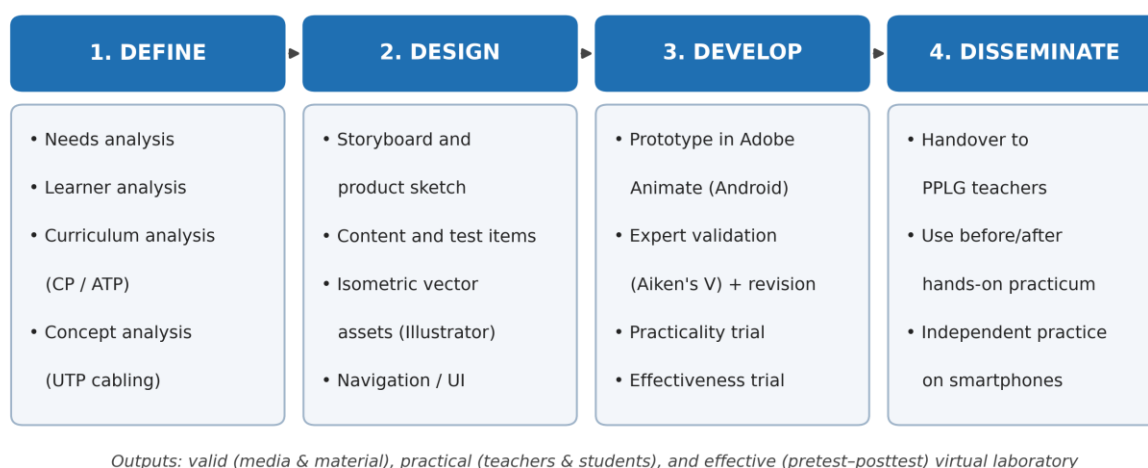


Figure 1. Development Framework of the Virtual Laboratory Based on the 4-D Model

Setting and Participants

This research was conducted at SMK Negeri 1 Rao Selatan, a government vocational school located in Pasaman Regency, West Sumatra, Indonesia, during the even semester of the 2025/2026 academic year. The school has one class at each grade level for students majoring in PPLG (Pengembangan Perangkat Lunak dan Gim). The participants were divided into four groups based on their roles in the research. The media expert group consisted of three lecturers from the Faculty of Engineering, Universitas Negeri Padang. The material expert group consisted of one lecturer and two PPLG teachers. The practitioner group, involved in evaluating the practicality of the product, consisted of two PPLG teachers and one vice-principal for curriculum. In addition, the entire Grade 10 PPLG class, consisting of 16 students, participated through total sampling. These students used the developed product and completed the pretest, posttest, and student practicality questionnaire.

Because the school offers only one PPLG class per grade, the accessible population for the trial consisted of all 16 Grade 10 PPLG students, and all of them were included (total sampling); random selection or assignment was not possible. An a priori power analysis for a two-tailed paired-samples *t*-test ($\alpha = .05$, power = .80) indicated that 15 participants were required to detect a large within-subject effect ($d_z = 0.80$; Faul et al., 2007), so the class size was adequate for this purpose. With $n = 16$, the smallest effect detectable with 80% power was $d_z \approx 0.75$; smaller effects could not be reliably detected, which is a further reason for treating the trial as a pilot. Separately, 25 Grade 11 PPLG students, who had studied the same subject in the previous year without the virtual laboratory, took part only in the tryout of the conceptual understanding test, which provided the data for item analysis (validity, difficulty, discrimination, and reliability). They were not a comparison or control group, and their scores were not compared with those of the Grade 10 class. Participants were between 16 and 18 years old.

The Developed Product

The product, Virtual Lab SMK N 1 Rao Selatan, is a mobile app (Android 11 to 15; minimum 1280 x 720 resolution) created with Adobe Animate and ActionScript 3. Background images, icons, and prac components were designed as isometric vectors in Adobe Illustrator. The app comprises eight modules (Table 1); introduction and main menu; usage instructions; learning outcomes and objectives; learning material; practicum module; learning video (after expert review); timed assessment; and developer profile. The practicum module provides three activities: identification of the components, cabling steps, and drag-and-drop simulation of UTP cable assembly (Figure 2) students in a simulation have to drag each wire into the right place to make straight-through and crossover cables. Automatic feedback is integrated in the workflow: students will not see the button for the next step until all wires are connected right, which means they have to correct any mistakes before they can continue. Everything material-simulation-evaluation can be done offline; only the YouTube video embedded needs the internet. This application should be used before and after hands-on crimping practice, not as a replacement for it.

Table 1. Characteristics and Development Stages of the Virtual Laboratory

Stage	Main activities	Output
Define	Needs analysis (teacher interview, classroom observation, student survey); learner analysis (Grade 10, ages 16–18); analysis of learning outcomes (CP) and objectives (ATP); concept analysis of UTP cabling	Specification: interactive, visual, self-paced simulation of UTP cabling for Android

Stage	Main activities	Output
Design	Product sketch and storyboard (12 screens); content and exercise drafting; isometric vector assets in Adobe Illustrator; navigation and interface design	Prototype design and asset library
Develop	Programming in Adobe Animate (ActionScript 3) for Android; expert validation (Aiken's V); revisions (background colors, simulation video, step-by-step job sheet, evaluation timer, additional evaluation items); practicality and effectiveness trials	Valid and revised product; practicality and effectiveness data
Disseminate	Handover of the application to PPLG teachers; use as a pre- and post-practicum support medium and for independent practice	Product adopted by the school

Note. CP = *Capaian Pembelajaran* (learning outcomes); ATP = *Alur Tujuan Pembelajaran* (learning objective sequence).

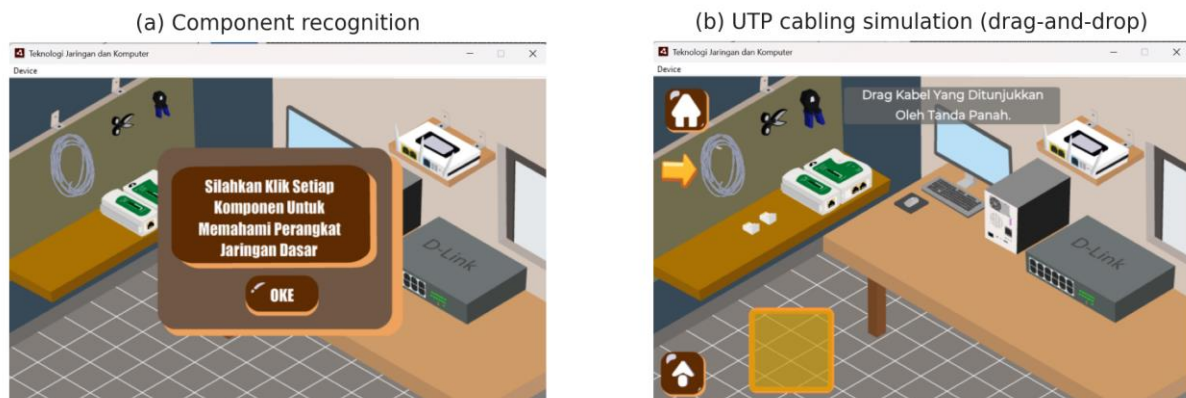


Figure 2. Interface of the Virtual Laboratory: (a) Component Recognition and (b) UTP Cabling Simulation

Note. Screenshots taken from the developed application (interface language: Indonesian). Panel (a) instructs students to click each component to learn about basic network devices; panel (b) instructs them to drag the cable indicated by the arrow.

Instruments

Validity questionnaires. The media form questionnaire was composed of three areas: display (7 questions), operation (7 questions), and usefulness (6 questions). These three areas had a total of 20 questions in the media form questionnaire. Material questionnaire had 20 questions too as it dealt with contents and teaching objectives, instructional quality, and language. All questions had to be responded to using a five-point scale (1 = *strongly disagree*, 5 = *strongly agree*).

Practicality questionnaires. Twenty items in relation to the five attributes of the computer programme, namely ease of use, time effectiveness, product attractiveness, media interpretation, and usefulness (each with four items) were ranked by teachers and students independently. The same five-point scale was implemented.

Conceptual understanding test. Multiple-choice questions tested on UTP cabling objectives (tools, cable types, pin order, and troubleshooting) at the memory, comprehension, and application levels of the revised Bloom's taxonomy (C1 C3). Each question had a right and a wrong answer and students' scores were given according to the scale of 0–100 points. An initial version of 30 multiple-choice questions was subjected to validation studies in terms of item validity (point-biserial correlation of each item against the total test score $> r_{critical} = 0.396$, $n = 25$, $\alpha = 0.05$), difficulty, discriminability and reliability (KR-20). Twenty-four of the items that passed the quality checks were retained for the final version of the test both as pretest and as posttest.

Procedure

Following expert validation and refinement of the teaching materials, students took a pretest and then used the virtual laboratory in eight regular sessions of four lesson periods (jam pelajaran, JP) each on the element of computer network technology, followed by a posttest. Students at the school used the application on tablets; meanwhile, the teacher provided the students with the installation file through the class WhatsApp group so that the students could get accustomed to a computer at home besides the one they get at school. This intervention is mainly for understanding the concepts: there is no physical hand practice, no crimping, between pretest and Posttest, so that the Posttest is a measure of learning without physical practice. The teacher and student practicality questionnaires were administered after the intervention. Within this single-group design, the main threats to internal validity are testing (identical items on both occasions), maturation and history over the eight sessions, the teacher's regular explanations, and unrecorded home use. The design controlled only for physical practice, since no crimping took place between the tests; the remaining threats could not be ruled out and are therefore considered in the interpretation of the gain and listed in the limitations.

Data Analysis

Validity. Aiken's (1985) coefficient, one of the ways of assessing reliability of responses or agreement of raters, was used on items to calculate $V = \sum s / [n(c, 1)]$; Here, $s = r$, lo , r is the rating, $lo = 1$ is the lowest category, $c = 5$ is the number of categories, and n is the number of raters. For aspect and overall coefficients, means of item-coefficients have been used. To validate the products, the researchers set a criterion of $V \geq 0.60$. However, as even stricter thresholds are used in other research papers ($V \geq 0.75$; Ahmad et al., 2024), the item-level results have been presented against both benchmarks.

Practicality. Practicality was calculated as a percentage of obtained score compared to the maximum score, and then it was grouped as very practical (81–100%), practical (61–80%), moderately practical (41–60%), less practical (21–40%), or impractical (0–20%).

Effectiveness. Criteria for effectiveness: classical completeness = at least 85% of the students reached the schools' minimum mastery level ($KKM = 75$), a paired-samples t -test of pretest and posttest scores ($\alpha = 0.05$). The data was found to follow normal distribution through Shapiro-Wilk normality test. According to Lakens (2013), we used the formula $d_z = M_{diff} / SD_{diff}$ to calculate effect sizes for paired samples. We used formula $\langle g \rangle = (M_{post}, M_{pre}) / (100, M_{pre})$ to compute the normalized gain of the class average. It was interpreted as low (<0.30), medium (0.30-0.70), or high (>0.70) after Hake (1998). Results were analyzed with IBM SPSS Statistics 25.

Ethical considerations. Researchers got the necessary clearance before the start of the study from Faculty of Engineering, Universitas Negeri Padang and Provincial Education Office and, also, from the school where the activities took place. Students, on their part, were not forced by the school or by the researchers to take part in the research. It was just a continuation of what they learn in class or, in other words, they took part in a learning program. Besides, student information and that of the validators were coded and anonymized in any case to prevent identification of participants before the data was analyzed and the results reported.

Results and Discussions

Define Stage

During classroom observation and a short teacher interview on February 11, 2026, we found that UTP cabling was taught mainly through slide presentations. Three major difficulties were identified: distinguishing straight-through from crossover cabling, understanding the function of each RJ-45 pin, and relating wire order to connection success. In the needs questionnaire ($n = 16$), [...] students ([...])% reported that they had little or no opportunity to practice cabling at home, mainly because they lacked appropriate tools and materials, and [...] students ([...])% expressed a need for a visual medium to help them prepare for practical sessions. The teacher's assessment records showed that [...] of 16 students ([...])% had not reached the mastery level ($KKM = 75$) on this topic. The curriculum analysis identified *assembling and troubleshooting basic UTP cabling* as the key learning outcome.

Design Stage

The design phase delivered a 12-screen storyboard that also included learning content and test questions. Moreover, an asset library with a networking workbench with a computer, switch, router, crimping tool, LAN tester, UTP cable and RJ-45 connectors in isometric design is also produced. Navigation buttons like home, next, back, settings, and exit were consistently presented on all the different screens of the program in such a way that students can use the software independently.

Development Stage

The Android app with a prototype was developed, packed and ready. Experts commented the prototype and this resulted in five major changes of the prototype. Specifically, the background colors change first; an explanatory video was added and then an audio track; the practicum was augmented with a step-by-step instruction and the job sheet; the time was set with a stop timer during evaluation; and, finally, a few evaluation items were inserted for good measure. The redesigned components recognition and cable simulation screens can be seen in Figure 2.

Validity

The results in Table 2 and Figure 3a show that all aspects were above the 0.60 threshold. Media validity was 0.83 for display, 0.82 for operation, usefulness 0.86, overall 0.84. Material validity ranged as follows: content and objectives 0.88, instructional quality 0.93, overall 0.91. At the level of items, these values for media items ranged from 0.75 to 0.92 in 20 items. All 20 items (100%) were at least 0.75, and 16 items (80%) reached or exceeded 0.83.

Table 2. Product Validity Results (Aiken's V)

Validation	Aspect	Items	Aiken's V	Category
Media (<i>n</i> = 3)	Display	7	0.83	Valid
	Operation	7	0.82	Valid
	Usefulness	6	0.86	Valid
	Overall	20	0.84	Valid
Material (<i>n</i> = 3)	Content and objectives		0.88	Valid
	Instructional quality		0.93	Valid
	Language		0.92	Valid
	Overall	20	0.91	Valid

Note. $V \geq 0.60$ = valid. Media validators were three engineering-faculty lecturers; material validators were one lecturer and two PPLG teachers. Media coefficients were recomputed from the raw item ratings and match the reported values.

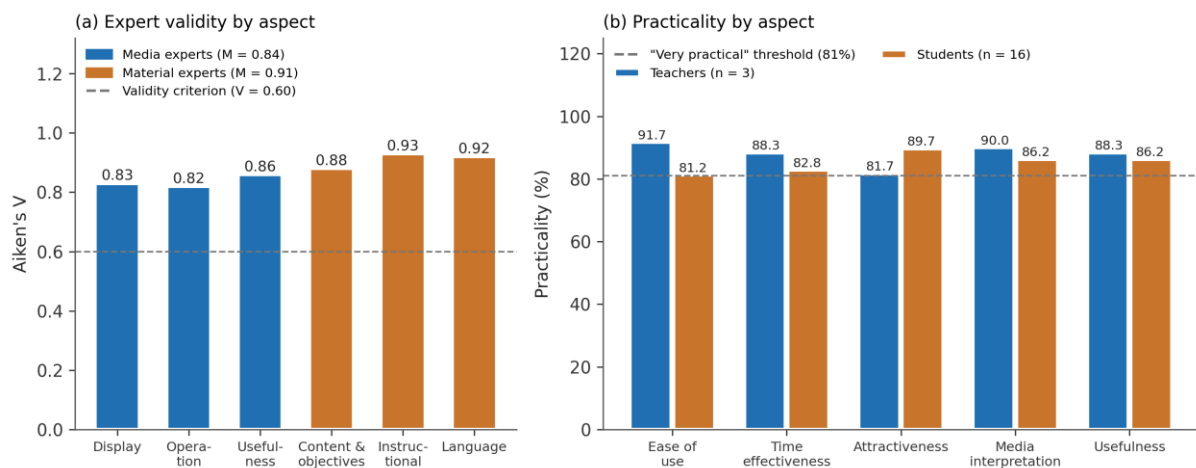
Practicality

All participants viewed the product as highly practical (Table 3; Figure 3b). Teachers gave the highest ratings to ease of use (91.67%) and media interpretation (90.00%) and the lowest rating to product attractiveness (81.67%). In contrast, students rated product attractiveness highest (89.69%) and ease of use lowest (81.25%).

Table 3. Practicality of the Virtual Laboratory

Assessment aspect	Teachers (%) (<i>n</i> = 3)	Students (%) (<i>n</i> = 16)
Ease of use	91.67	81.25
Time effectiveness	88.33	82.81
Product attractiveness	81.67	89.69
Media interpretation	90.00	86.25
Usefulness	88.33	86.25
Overall	88.00	85.25
Category	Very practical	Very practical

Note. Each aspect comprised four items rated on a five-point scale; values are percentages of the maximum score (teachers: 60 per aspect, 300 overall; students: 320 per aspect, 1,600 overall).

**Figure 3.** Validity and Practicality Results by Aspect

Note. (a) Aiken's V for media and material aspects; the dashed line marks the validity criterion ($V = 0.60$). (b) Practicality percentages for teachers (*n* = 3) and students (*n* = 16); the dashed line marks the lower bound of the "very practical" category (81%). Data from the study.

Effectiveness

Test quality. Out of 30 tryout items, only 24 were valid since the correlation (*r*) of those items with the total score ranged from 0.509 to 0.874 (above *r*-critical = 0.396), and the other six were discarded (items 4, 5, 6, 16, 23, 30). Items that were eliminated were very easy ones whose difficulty did not match, so, items 5 and 30 were excluded because of their very high ease and negative discrimination of item difficulty. (Table 4; Figure 4). Of the 24 retained items, 21 (87.5%) were of moderate difficulty and 3 (12.5%) were easy (items 17, 20, and 25), with difficulty indices (*P*) ranging from 0.36 to 0.80. The reliability of the initial 30-item tryout was $KR-20 = 0.922$ whereas for the 24 retained items the reliability was $KR-20 = 0.937$ estimated by item intercorrelations.

Table 4. Item Analysis of the Conceptual Understanding Test (Tryout, *n* = 25)

Indicator	Criterion	Result
Item validity	$r_{it} > 0.396$	24 valid; 6 invalid (items 4, 5, 6, 16, 23, 30)

Indicator	Criterion	Result
Item-total correlation, retained items	-	0.509 to .874
Difficulty index (<i>P</i>), retained items	0.30–0.70 moderate; > 0.70 easy	21 moderate, 3 easy (items 17, 20, 25); range 0.36–0.80
Discrimination, retained items	≥ 0.40 good	0.45 to 0.85 (all good or excellent)
Discrimination, discarded items	-	–0.23 to 0.28 (two negative: items 5 and 30)
Reliability (KR-20)	≥ 0.70	0.922 (30 items); 0.937 (24 retained items)

Note. Discrimination values are corrected item-total correlations from SPSS. Full item statistics appear in Appendix Table A1.

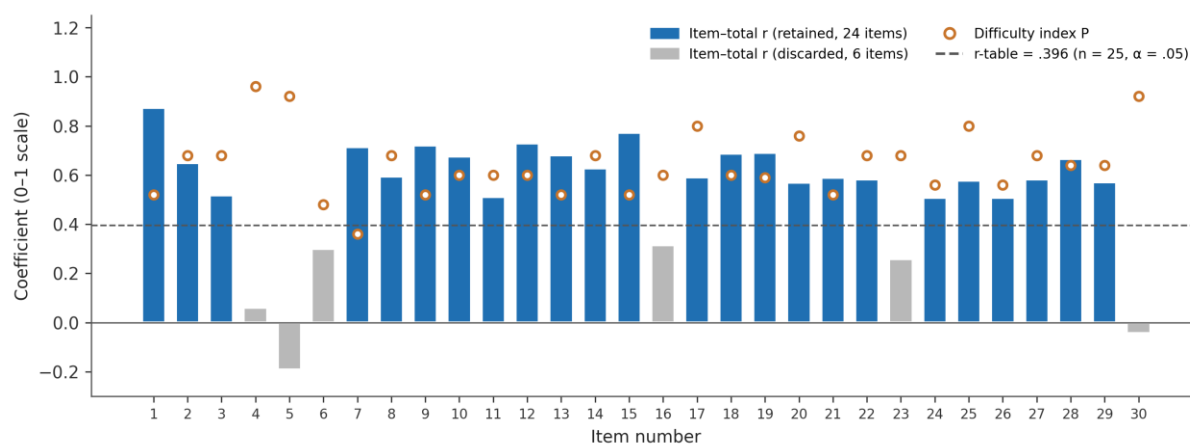


Figure 4. Item-Total Correlations and Difficulty Indices of the 30 Tryout Items

Note. Bars show item-total correlations (retained items in blue, discarded items in gray); circles show difficulty indices. The dashed line marks $r\text{-critical} = 0.396$ ($n = 25$, $\alpha = 0.05$). Data from the tryout ($n = 25$).

Pretest-posttest comparison. In essence, Table 5 and Figure 5 capture the effectiveness outcomes. The average score of the pretest was 62.50 (SD = 12.73; range 41.67–83.33), whereas the average posttest score reached 85.68 (SD = 8.47; range 70.83–100.00). A Shapiro-Wilk test detected neither a significant departure from normality for the two groups (pretest $W = 0.915$; posttest $W = 0.925$; both $p > 0.05$). The difference between the pre- and the posttests was statistically significant according to a paired-samples t -test, $t(15) = 8.14$, $p < 0.001$. The average improvement was 23.18 points, 95% CI [17.11, 29.24], which corresponds to about 5.6 more correctly answered items out of 24. According to the measure of standardized effect, it was large, $d_z = 2.04$, with an average group normalized gain of the class as $\langle g \rangle = 0.62$, a medium-sized gain. The posttest score showed less variation compared to the pretest, with the lowest posttest score (70.83) being 29.16 points higher than the lowest pretest score of 41.67. Following the intervention, 15 out of 16 students (93.75 %) achieved the level of mastery (KKM = 75), surpassing the 85 % classical completeness threshold.

Table 5. Pretest-Posttest Effectiveness Results ($n = 16$)

Measure	Pretest	Posttest	Statistic
M (SD)	62.50 (12.73)	85.68 (8.47)	-
Minimum-maximum	41.67–83.33	70.83–100.00	-
95% CI of the mean	[55.72, 69.28]	[81.17, 90.19]	-
Shapiro-Wilk W	0.915	0.925	both $p > .05$; $df = 16$
Mean difference (post – pre)	-	-	23.18, 95% CI [17.11, 29.24]
Paired-samples t -test	-	-	$t(15) = 8.14$, $p < .001$
Effect size	-	-	$d_z = 2.04$
Normalized gain $\langle g \rangle$	-	-	0.62 (medium)
Students $\geq$ KKM (75)	-	15 (93.75%)	Criterion $\geq$ 85% met

Note. Scores are on a 0–100 scale (24 items; one item = 4.17 points). The same items were used on both occasions. $d_z = M_{diff}/SD_{diff}$ (Lakens, 2013); $\langle g \rangle = (M_{post} - M_{pre})/(100 - M_{pre})$ (Hake, 1998).

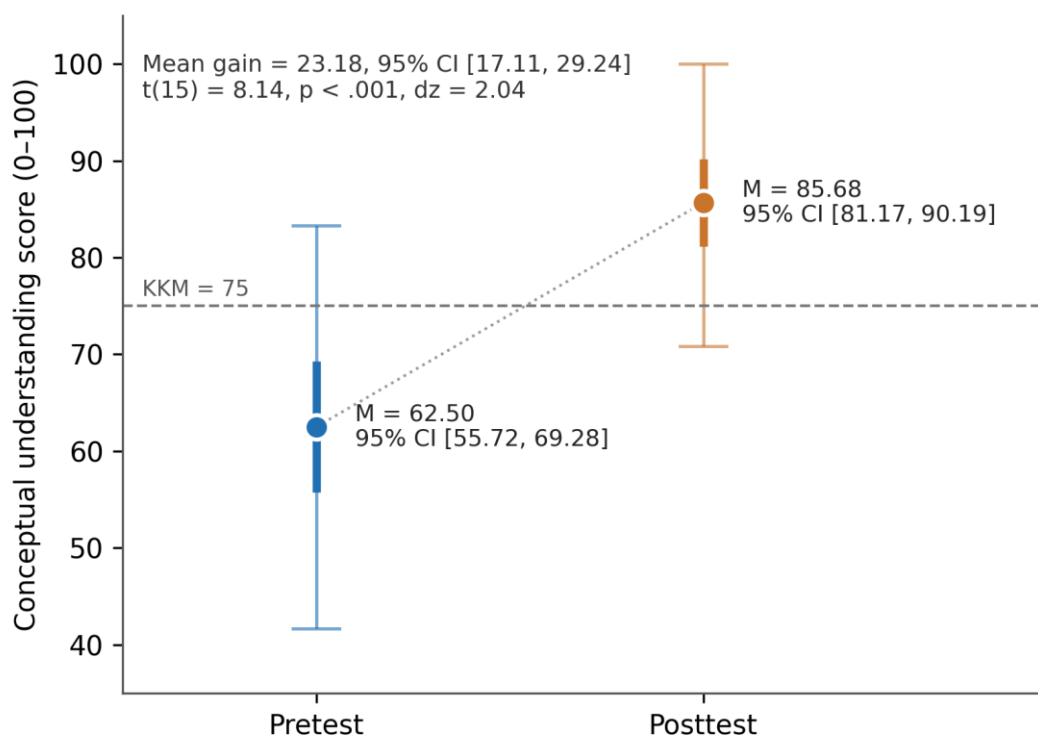


Figure 5. Comparison of Pretest and Posttest Scores

Note. Points show means with 95% confidence intervals; thin vertical lines show the observed score range (minimum-maximum); the dashed line marks the mastery criterion (KKM = 75). $n = 16$.

Dissemination Stage

A well-checked app was given to the PPLG teachers of the school as a supplementary computer network technology element. It is a tool teachers and the whole class can use for learning components and cabling steps before a practical lesson. It can also be installed by the students on their Android phones for self-study and revision. The file is still distributed via the class representative only, and the app has not yet been published in an online marketplace like Google Play.

Validity: Expert Agreement on Content and Interface

Virtual laboratory items were validated with media having a validity coefficient of 0.84 and material being 0.91. Every media item was at least 0.75 or more. The findings may show that the product's depiction of the cabling workbench and its agreement with the learning objectives were considered adequate by the combination of both technical and pedagogical experts. The larger material than media coefficient agrees with the kind of modifications requested by the media experts which had to do with the visual and operational features (background color, instructions, timer) rather than getting to accuracy aspects of the content. Aiken's V-based validation in the Vocational electrical power electronics context that resulted in high agreement from experts (Yanto, Hastuti, et al., 2023) would support this statement. Similarly, Android media for the network services developed through the 4-D method was considered as "very valid" by the assessors (Novaliendry et al., 2021). A word of caution needs to be mentioned: since there were only three raters for each instrument, Aiken's (1985) probability tables would only weakly support item V values of 0.75 being valid. As a result, expert validity is more of a prerequisite for using materials in the classroom rather than being a demonstration of the impact on learning.

Practicality: Different Priorities of Teachers and Students

The majority of both practitioners (88.00%) and students (85.25%) rated the product as very practical. At the same time, they were quite different in their profiles. Teachers considered that the product's feature of being effortless as well as the way it helped the understanding of abstract concepts was highly relevant. On the other hand, students rated ease of use lowest (81.25%) and product attractiveness highest (89.69%). Maybe it could be that the teachers considered the product more as an instructional aid and the students the product in a way more as an operating machine that a learner is facing for the first time a simulation that is being dragged and dropped on a small screen. The job sheet and the instructions that have come out after the review might have made it easier but not yet totally solved the problem. This view is in tune with technology acceptance data from vocational students where perceived ease of use and usefulness predicted the intention to use a virtual laboratory

(Yanto, Sukardi, et al., 2023). In addition, the view is in harmony with the idea that teacher support and the virtual laboratory do not work separately but together (Hassan et al., 2022). In actual terms, the students' lower ratings on ease of use point to an idea that a brief teacher-led demo or a short tutorial at the first session would increase students' ability to work separately.

Effectiveness: Why a Virtual Laboratory May Support Conceptual Understanding

Posttest scores were significantly higher than pretest scores, indicating a mean gain of about 23.18 points. This statistically significant difference was shown by a t value with 15 degrees of freedom of 8.14 (which corresponds to a p value significantly less than .001) and an effect size d_z of 2.04. Most notably, almost all of the group, i.e., 93.75%, actually reached the mastery criterion. Given the fact that there was not a single hands-on crimping between the tests, the gain cannot be attributed to physical practice; however, as discussed below, it may still partly reflect regular instruction, testing, and maturation. In fact, one of the results of this change is a narrower distribution of scores which is usually interpreted as a positive trend in students' performance: the lowest performing students are getting closer to the level of mastery. This association may be explained by three different mechanisms. The very first explanation is based on the way the isometric workbench makes a set of invisible or easily overlooked interdependencies very clear. It gives us a picture of a complete and correct sequence: what tool one uses at what stage of the work, how the eight strands are matched up with the respective connector pins, and what is it that differentiates a straight-through cable from the crossover cable, all of which are very difficult to observe physically. This way, virtual or simulated laboratory work (de Jong et al., 2013), which has made previously unobservable phenomena visible, is one of its unique features or characteristics. As for the next mechanism, it is related to the drag-and-drop simulation element in the application which transforms a typically observer passive type of activity into something that students have to get involved in personally. With the immediate feedback, mistakes do not merely mean loss of resources or even time but become learning materials and students have the option to redo the exercise again if they wish and without running out of cables or plugs. Last, the different segments (materials, component recognition, steps, simulation) of the application are arranged following the basic idea of segmented, pre-trained, and signaling which are part of the principles of multimedia design and are considered best practices according to Mayer (2024) and Noetel et al. (2022). That is, these design ideas are implemented in the teaching material and through those means the cognitive load on the learner's side, also known as extraneous load, is minimized. Extraneous load is part of our mental effort that is not directly relevant to the task at hand or the material. It has more to do with the way information is presented or packaged (a very visual or complex representation for example). This load is what the designers are concerned with since they have the power to shape the content so that the learning becomes as simple, efficient, and effective as possible.

However, the large effect should be cautiously interpreted. Paired-design effect sizes (d_z) usually exceed between-group effects because change scores' variability is used for standardization (Lakens, 2013). So, one might wonder if these two values are actually comparable. It is difficult to directly compare meta-analytic estimates of $g = 0.686$ for engineering virtual laboratories (Li & Liang, 2024) or $g = 0.383$ for virtual technology chemistry (Song et al., 2025). Furthermore, without a comparison group, it is difficult to know if the gain is mainly due to regular teacher explanation, the students' familiarity with the test items, and maturation over the eight sessions (Knapp, 2016). Controlled Indonesian SMK studies provide a good point of reference. In one example, the use of an Android virtual laboratory led to a greater N-gain compared to traditional teaching (78.19% vs 54.07%; Niswah et al., 2024). The normalized gain of the current study (0.62, 62%) is right in the middle of the experimental and control groups of that study, indicating that the improvement found here is quite realistic rather than exaggerated. In another, combining a science virtual laboratory with demonstration methods improved lower-secondary students' scientific literacy (Lestari et al., 2023). The pattern of results reported here matches those of the other research, and the size does not seem likely to be due to the intervention product alone. The direction of the gain is also consistent with meta-analytic evidence that mobile learning significantly enhances learning gains (Garzón et al., 2025), although the present design cannot isolate the contribution of the mobile format itself.

Why Isometric Rather Than Immersive Visualization?

A crucial aspect of the design was choosing a form of isometric (pseudo-3D) drawing rather than fully three-dimensional, immersive environments that are the subject of VR simulations. Research has shown that richness of visual material does not necessarily mean better learning, for example when one uses immersive virtual reality presence may go up at the expense of learning. This is accompanied with increased cognitive load (Makransky et al., 2019). Studies of the augmented reality that made use of 3D visualization were associated with less significant knowledge changes (Chang et al., 2022). When vocational learners were subjected to immersive VR, their objective knowledge scores were lower than when paper materials were used (Thomann et al., 2024). By showing devices and tools together on the screen an isometric view maintains the relation they have in space, the screen is small, but the picture still remains legible it runs on SMK students' android devices. Such a choice

could account for students finding it attractive without getting visually fatigued from its appearance. Yet, the testable hypothesis is the only way to find out that different representational formats are not comparable directly to each other.

Contribution to Vocational and PPLG Education

When it comes to vocational education, the study illustrates that a low-cost smartphone simulation can potentially overcome two major restrictions of SMK: limited equipment and limited repetition. Such limitation is a common problem in the initiatives for virtual laboratories in resource-poor schools and universities (Mwansa et al., 2024; Shambare & Simuja, 2022). In the case of the PPLG program, the product targets students who are mainly oriented towards software but still need to develop the infrastructure fundamentals. For these students, pre-conceptual training prior to a single practical exercise can be particularly useful. The virtual laboratory is a **support tool and not a substitute for physical exercises**. Some tasks like Crimping, cable testing, fault finding require psychomotor as well as hands-on skills that a touchscreen cannot train. Research that shows that the combination of real, virtual activities outperforms either alone backs up the blended learning concept (Wörner et al., 2022). A virtual laboratory provides understanding of concepts and how things are done while a physical laboratory develops the skill and the equipment is there to verify if it is working or not. Apart from the concern that virtual laboratories at this point still can't fully replace real hands-on laboratories (Li & Liang, 2024) such sequencing would be a good resolution.

Theoretical Implications

Theoretically, the findings extend the cognitive theory of multimedia learning to a psychomotor-oriented vocational domain. The gain occurred without physical practice, which is consistent with the view that well-designed visual and verbal representations support schema construction for procedural knowledge (Mayer, 2024; Sweller et al., 2019). At the same time, the results qualify the assumption that higher visual fidelity produces better learning: a low-fidelity isometric representation was rated attractive and was associated with a large gain, whereas more immersive media have produced smaller or even negative effects on knowledge (Makransky et al., 2019; Thomann et al., 2024). This discrepancy suggests that, for introductory cabling concepts, representational clarity and interactivity may matter more than realism, a proposition that should be tested by comparing isometric, 3D, and augmented-reality versions of the same content. The results also differ from the meta-analytic finding of no overall advantage of virtual over physical investigation (Muilwijk & Lazonder, 2023). Because the present study did not compare virtual with physical practice, it supports a sequencing claim rather than a substitution claim, in line with Wörner et al. (2022). In practice, teachers are therefore recommended to use the virtual laboratory before and after, not instead of, hands-on crimping sessions.

Conclusions

This study developed an Android-based isometric virtual laboratory to support Grade 10 PPLG students' conceptual understanding of UTP cabling. With regard to validation, experts judged the product valid (media $V = 0.84$; material $V = 0.91$), and practitioners and students rated it very practical (88.00% and 85.25%, respectively). These results establish the quality of the product's content and interface and its usability; they are not evidence of its effect on learning. With regard to effectiveness, the evidence is preliminary. In a pilot one-group pretest–posttest trial, mean conceptual test scores rose from 62.50 to 85.68 ($t(15) = 8.14$, $p < .001$, $d_z = 2.04$, $\langle g \rangle = 0.62$), and 15 of 16 students (93.75%) reached the mastery level. Because there was no control group, this gain shows an association between use of the product and higher scores, not a causal effect, and it may also reflect regular instruction, testing, and maturation. Meeting the classical completeness criterion therefore indicates that the learning target was reached in this class, not that the product alone caused it to be reached. The main contribution of the study is a documented, low-resource design for simulating physical network cabling on smartphones: the application runs offline on students' existing Android devices, consumes no cables or connectors during practice, and is reported across the full 4-D cycle. Its intended role is to prepare students conceptually before hands-on practice and to reinforce learning afterwards in vocational schools with limited workshop facilities. The interpretation of these results is subject to several limitations. Firstly, as the experimental study employed a one-group pre, posttest design without a control group, it is not possible to attribute the change in students' performance to the virtual lab alone. One also cannot be fully certain whether it is only the virtual lab that was the source of the improvement. Secondly, the sample was relatively small (16 students) and was selected from only one class in one school. Thus, it is hard to say whether these results would hold if they were replicated in other SMKs, programs, and regions. Thirdly, the content was confined to the UTP cabling segment of the computer network technology unit. No simulation was done with topologies, addresses, and a configuration. Fourth, the game runs only on Android platform, which renders students with non-compatible devices out. Fifth, the lab product facilitates but doesn't substitute for manual hands-on practice. Moreover, psychomotor skills in cabling are not among the skills tested and measured. Sixth, identical test items

were presented to students on both the pretest and the posttest students might have been able to remember their earlier answers and a delayed test was not used to check memory retention. Seventh, home usage of the app was not recorded and the amount of private practice students performed could not be determined. Future empirical work would benefit from using quasiexperimental or randomized methods with a control group. (e.g., lectures plus practical sessions vs. a virtual lab plus physical lab). Research should use both test versions simultaneously and collect data on individual screen time. They should also measure psychomotor performance by evaluating the actual crimping task with hands. Delayed posttests should be included in the study to measure retention. Bringing a lab to topology, IP addressing, and troubleshooting scenarios could be a step toward developing different platforms, web-based or cross-platform, and using learning analytics from interaction logs (Elmoazen et al., 2023). These will provide the basis for further evidence. Carrying out a comparison between isometric drawings, full 3-D views, and augmented-reality versions of the same content can demonstrate what media is most effective for supporting a vocational education beginner. In order to help teachers best introduce various tools, the virtual environment can be scheduled as first introduction to the hands-on work and the pin order can be explained in that session too. Later, the virtual environment can be used to detect the mistakes learners make. In schools, especially where equipment is scarce, mobile phone simulations are a low-resource way to complement laboratory equipment by preparing students before hands-on sessions, but they cannot replace that equipment. Virtual laboratory that is locally produced has been rated as very convenient and the students quite like them in the Indonesia context (Sriadhi et al., 2022). From the PPLG sample, curriculum experts know that infrastructure basics necessary for software-reliant programs can be met by making short and focused simulational videos instead of spending lots of time conducting laboratory experiments.

References

- Abdrabou, A., & Shakhathreh, W. (2021). On assessment and evaluation of teaching computer networks to electrical engineering students by the aid of a lab course. *Journal of Technology and Science Education*, 11(2), 388–402. <https://doi.org/10.3926/jotse.1186>
- Ahmad, N. A., Mayouf, A. A., Elias, N. F., & Mohamed, H. (2024). Learning management system instrument development based on Aiken's V technique. *International Journal of Evaluation and Research in Education*, 13(5), 3211–3219. <https://doi.org/10.11591/ijere.v13i5.28925>
- Aiken, L. R. (1985). Three coefficients for analyzing the reliability and validity of ratings. *Educational and Psychological Measurement*, 45(1), 131–142. <https://doi.org/10.1177/0013164485451012>
- Badan Pusat Statistik. (2025, May 5). *Keadaan ketenagakerjaan Indonesia Februari 2025* [Labor force situation in Indonesia, February 2025] [Press release]. <https://www.bps.go.id/id/pressrelease/2025/05/05/2432/keadaan-ketenagakerjaan-indonesia-februari-2025.html>
- Cattaneo, A. A. P., Antonietti, C., & Rausedo, M. (2022). How digitalised are vocational teachers? Assessing digital competence in vocational education and looking at its underlying factors. *Computers & Education*, 176, Article 104358. <https://doi.org/10.1016/j.compedu.2021.104358>
- Chang, H.-Y., Binali, T., Liang, J.-C., Chiou, G.-L., Cheng, K.-H., Lee, S. W.-Y., & Tsai, C.-C. (2022). Ten years of augmented reality in education: A meta-analysis of (quasi-) experimental studies to investigate the impact. *Computers & Education*, 191, Article 104641. <https://doi.org/10.1016/j.compedu.2022.104641>
- de Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science*, 340(6130), 305–308. <https://doi.org/10.1126/science.1230579>
- Dong, Z., Chiu, M. M., Zhou, S., & Zhang, Z. (2024). The effect of mobile learning on school-aged students' science achievement: A meta-analysis. *Education and Information Technologies*, 29(1), 517–544. <https://doi.org/10.1007/s10639-023-12240-3>
- Elmoazen, R., Saqr, M., Khalil, M., & Wasson, B. (2023). Learning analytics in virtual laboratories: A systematic literature review of empirical research. *Smart Learning Environments*, 10(1), Article 23. <https://doi.org/10.1186/s40561-023-00244-y>
- Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39(2), 175–191. <https://doi.org/10.3758/BF03193146>
- Garzón, J., Burgos, D., Kinshuk, & Tlili, A. (2025). Mobile learning significantly enhances student learning gains: A meta-analysis and research synthesis. *Computers & Education*, 238, Article 105415. <https://doi.org/10.1016/j.compedu.2025.105415>
- Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64–74. <https://doi.org/10.1119/1.18809>

- Hamzah, M. L., Ambiyar, A., Rizal, F., Simatupang, W., Irfan, D., & Refdinal, R. (2021). Development of augmented reality application for learning computer network device. *International Journal of Interactive Mobile Technologies*, 15(12), 47–64. <https://doi.org/10.3991/ijim.v15i12.21993>
- Hassan, J., Devi, A., & Ray, B. (2022). Virtual laboratories in tertiary education: Case study analysis by learning theories. *Education Sciences*, 12(8), Article 554. <https://doi.org/10.3390/educsci12080554>
- Knapp, T. R. (2016). Why is the one-group pretest–posttest design still used? *Clinical Nursing Research*, 25(5), 467–472. <https://doi.org/10.1177/1054773816666280>
- Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, 4, Article 863. <https://doi.org/10.3389/fpsyg.2013.00863>
- Layadi, S., Huguet, P., Pavic, K., & Chevalère, J. (2026). Virtual reality in education: A stratified meta-analysis of experimental rigor and bias. *Educational Psychology Review*, 38(1), Article 50. <https://doi.org/10.1007/s10648-026-10130-x>
- Lestari, D. P., Supahar, Paidi, Suwarjo, & Herianto. (2023). Effect of science virtual laboratory combination with demonstration methods on lower-secondary school students' scientific literacy ability in a science course. *Education and Information Technologies*, 28(12), 16153–16175. <https://doi.org/10.1007/s10639-023-11857-8>
- Li, J., & Liang, W. (2024). Effectiveness of virtual laboratory in engineering education: A meta-analysis. *PLOS ONE*, 19(12), Article e0316269. <https://doi.org/10.1371/journal.pone.0316269>
- Luse, A., & Rursch, J. (2021). Using a virtual lab network testbed to facilitate real-world hands-on learning in a networking course. *British Journal of Educational Technology*, 52(3), 1244–1261. <https://doi.org/10.1111/bjet.13070>
- Makransky, G., Terkildsen, T. S., & Mayer, R. E. (2019). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. *Learning and Instruction*, 60, 225–236. <https://doi.org/10.1016/j.learninstruc.2017.12.007>
- Mayer, R. E. (2024). The past, present, and future of the cognitive theory of multimedia learning. *Educational Psychology Review*, 36(1), Article 8. <https://doi.org/10.1007/s10648-023-09842-1>
- Muiliwijk, S. E., & Lazonder, A. W. (2023). Learning from physical and virtual investigation: A meta-analysis of conceptual knowledge acquisition. *Frontiers in Education*, 8, Article 1163024. <https://doi.org/10.3389/educ.2023.1163024>
- Mwansa, G., Ngandu, M. R., & Dasi, Z. S. (2024). Enhancing practical skills in computer networking: Evaluating the unique impact of simulation tools, particularly Cisco Packet Tracer, in resource-constrained higher education settings. *Education Sciences*, 14(10), Article 1099. <https://doi.org/10.3390/educsci14101099>
- Niswah, A. K., Roemintoyo, R., & Rejekiingsih, T. (2024). Development of Android-based virtual laboratory media at vocational school: Effects on students' cognitive skills. *International Journal of Evaluation and Research in Education*, 13(1), 503–510. <https://doi.org/10.11591/ijere.v13i1.25470>
- Noetel, M., Griffith, S., Delaney, O., Harris, N. R., Sanders, T., Parker, P., del Pozo Cruz, B., & Lonsdale, C. (2022). Multimedia design for learning: An overview of reviews with meta-meta-analysis. *Review of Educational Research*, 92(3), 413–454. <https://doi.org/10.3102/00346543211052329>
- Novaliendry, D., Huda, A., Annisa, L., Costa, R. R. K., Yudhistira, & Eliza, F. (2023). The effectiveness of web-based mobile learning for mobile subjects on computers and basic networks in vocational high schools. *International Journal of Interactive Mobile Technologies*, 17(9), 20–30. <https://doi.org/10.3991/ijim.v17i09.39337>
- Novaliendry, D., Huda, A., Sanita, D., Putra, D. A., Nasution, M. D. F., Putra, R. S., & Hidayati, R. N. (2021). Android-based network services application learning media for vocational high schools. *International Journal of Interactive Mobile Technologies*, 15(20), 83–100. <https://doi.org/10.3991/ijim.v15i20.23745>
- Reeves, S. M., & Crippen, K. J. (2021). Virtual laboratories in undergraduate science and engineering courses: A systematic review, 2009–2019. *Journal of Science Education and Technology*, 30(1), 16–30. <https://doi.org/10.1007/s10956-020-09866-0>
- Roll, M. J. J., & Ifenthaler, D. (2021). Multidisciplinary digital competencies of pre-service vocational teachers. *Empirical Research in Vocational Education and Training*, 13, Article 7. <https://doi.org/10.1186/s40461-021-00112-4>
- Santos, M. L., & Prudente, M. (2022). Effectiveness of virtual laboratories in science education: A meta-analysis. *International Journal of Information and Education Technology*, 12(2), 150–156. <https://doi.org/10.18178/ijiet.2022.12.2.1598>
- Shadish, W. R., Cook, T. D., & Campbell, D. T. (2002). *Experimental and quasi-experimental designs for generalized causal inference*. Houghton Mifflin.
- Shambare, B., & Simuja, C. (2022). A critical review of teaching with virtual lab: A panacea to challenges of conducting practical experiments in science subjects beyond the COVID-19 pandemic in rural schools

- in South Africa. *Journal of Educational Technology Systems*, 50(3), 393–408. <https://doi.org/10.1177/00472395211058051>
- Song, Q., Li, M., Zhang, Z., & Zhou, Q. (2025). Learning effectiveness of virtual technologies in chemistry using a three-level meta-analysis. *Education and Information Technologies*, 30(11), 14737–14759. <https://doi.org/10.1007/s10639-025-13321-1>
- Sriadhi, S., Hamid, A., & Restu, R. (2022). Web-based virtual laboratory development for basic practicums in science and technology. *TEM Journal*, 11(1), 396–402. <https://doi.org/10.18421/TEM111-50>
- Suharno, Pambudi, N. A., & Harjanto, B. (2020). Vocational education in Indonesia: History, development, opportunities, and challenges. *Children and Youth Services Review*, 115, Article 105092. <https://doi.org/10.1016/j.childyouth.2020.105092>
- Sukardjo, M., Khasanah, U., Rahmat, S. T., Khaerudin, & Setiawan, B. (2023). Virtual laboratory design for learning electro-pneumatic practices in vocational high schools. *European Journal of Educational Research*, 12(2), 719–737. <https://doi.org/10.12973/eu-jer.12.2.719>
- Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive architecture and instructional design: 20 years later. *Educational Psychology Review*, 31(2), 261–292. <https://doi.org/10.1007/s10648-019-09465-5>
- Thiagarajan, S., Semmel, D. S., & Semmel, M. I. (1974). *Instructional development for training teachers of exceptional children: A sourcebook*. Indiana University. <https://eric.ed.gov/?id=ED090725>
- Thomann, H., Zimmermann, J., & Deutscher, V. (2024). How effective is immersive VR for vocational education? Analyzing knowledge gains and motivational effects. *Computers & Education*, 220, Article 105127. <https://doi.org/10.1016/j.compedu.2024.105127>
- Usmeldi, U., & Amini, R. (2022). Creative project-based learning model to increase creativity of vocational high school students. *International Journal of Evaluation and Research in Education*, 11(4), 2155–2164. <https://doi.org/10.11591/ijere.v11i4.21214>
- Wörner, S., Kuhn, J., & Scheiter, K. (2022). The best of two worlds: A systematic review on combining real and virtual experiments in science education. *Review of Educational Research*, 92(6), 911–952. <https://doi.org/10.3102/00346543221079417>
- Yanto, D. T. P., Hastuti, Zaswita, H., Kabatiah, M., Sukardi, & Ambiyar. (2023). Validity test analysis of virtual laboratory-based job sheet for power electronics course. *International Journal of Information and Education Technology*, 13(9), 1469–1477. <https://doi.org/10.18178/ijiet.2023.13.9.1951>
- Yanto, D. T. P., Sukardi, Kabatiah, M., Zaswita, H., & Candra, O. (2023). Analysis of factors affecting vocational students' intentions to use a virtual laboratory based on the technology acceptance model. *International Journal of Interactive Mobile Technologies*, 17(12), 94–111. <https://doi.org/10.3991/ijim.v17i12.38627>