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Developing a Virtual Laboratory on Computer Assembly to Improve SMK Students' Motivation and Independent Learning Skills Using the ADDIE Model

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Abstract: Students' motivation for independent learning remains low, partly due to the lack of engaging and high quality learning media. This study aims to develop a virtual laboratory for computer assembly to support high school students' independent learning. The virtual lab was developed using the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation). Data were collected through observation, interviews, and questionnaires based on the ISO 25010 instrument. Evaluation involved two media experts and ten users (two teachers and eight students), yielding feasibility scores of 110.08 and 111.8, both rated "Very Feasible." A small-group trial with 60 students (experimental and control groups) showed a significant difference in learning outcomes (t-test sig. = 0.000), with the experimental group scoring higher (M = 51.79) than the control group (M = 36.67). These results suggest that the virtual lab has the potential to enhance students' independent learning abilities in the short term. However, caution is needed in interpreting these results, as other factors such as novelty effects, teacher influence, or students' prior knowledge may also have contributed.

Keywords: Virtual Learning Experience; Virtual Laboratorium; ADDIE; Independent Learning Skills.

INTRODUCTION

The rapid advancement of Information and Communication Technology (ICT) has brought significant changes across various aspects of life, including education. In this context, the education system is required to adapt to the evolving digital pedagogy and technology-based learning environments in order to produce graduates who are technologically literate. In Indonesia, the integration of ICT into education has become a strategic agenda to enhance national competitiveness in the global era (Bachtiar, 2022). This policy direction aligns with the Strategic Plan of the Ministry of Education, Culture, Research, and Technology (Muhajarah & Sulthon, 2020).

However, several challenges persist in implementing ICT, particularly in vocational high schools (SMK). Studies have shown that limited infrastructure, low digital competence among educators, and a lack of appropriate digital learning media tailored to vocational education are major barriers to effective ICT integration (Antonietti et al., 2022; Bingimlas, 2009; Timotheou et al., 2023). These challenges are especially evident in technical subjects such as computer assembly, where hands-on practice is essential but often hindered by the lack of equipment and high costs (Zhou et al., 2022). As a result, students experience decreased motivation and lack opportunities for self-directed learning (Kim et al., 2021; Onah et al., 2021; Zhu et al., 2022).

Along with the digital transformation, the demands on graduate competencies have also changed. One of the essential skills in the 21st century is the ability to learn independently (independent learning or self-regulated learning / SRL) (Meilina et al., 2023). Independent learning refers to an individual's ability to proactively take initiative, plan, manage, monitor, and evaluate their own learning process effectively without constantly relying on external direction (Pulatovna, 2024; van Hout-Wolters et al., 2000). This concept aligns with the Indonesian Merdeka Belajar policy, which promotes a paradigm shift from teacher-centered learning to student-centered learning (Tiwow et al., 2025). Within this framework, students are encouraged to be more active, critical, and independent in exploring various learning resources, while teachers transition into the role of learning facilitators (Bonner et al., 2017).

Developing self-directed learning is a crucial goal in schools, aiming to produce graduates who possess not only technical knowledge and skills but also adaptability, intrinsic motivation, and the ability to engage in lifelong learning. This is increasingly important in response to the development of digital pedagogy and the needs of a dynamic labor market (Bachtiar, 2022). Digital based learning, with its flexibility and accessibility, is considered effective in fostering self-directed learning by allowing students to learn at their own pace and in harmony with their personal learning styles (Dikilitas & Fructuoso, 2023; Lee & Chang, 2025).

However, conventional learning methods that are still widely applied often face challenges in fostering students' independence and motivation to learn. The lecture dominated approach tends to make students passive and less involved in the learning process (Bogar et al., 2023). Limited access to physical learning resources, such as adequate laboratories or practical materials, especially in remote areas or in special situations such as a pandemic, is also a significant obstacle to meaningful learning, especially in science and technology (Forde & OBrien, 2022; Oliveira et al., 2021). In addition, the curriculum, which is sometimes rigid and does not provide enough space for independent exploration, can also hinder the development of students' potential and independence (Thompson et al., 2021).

On the other hand, the advancement of Information and Communication Technology (ICT) has introduced a variety of digital tools and platforms such as online learning resources, interactive media, and virtual laboratories that support flexibility, accessibility, and individualized learning exploration (Samoylenko et al., 2022; Ukpe, 2023). These features are essential in promoting self-regulated learning, as they allow students to exercise greater control over their own learning processes. The accelerated adoption of technology during the COVID-19 pandemic further demonstrated the scalability of these tools and improved users' digital literacy and familiarity with their use (Subramanian et al., 2022). Thus, the development of ICT not only aligns with the increasing need for independent learners, but also offers innovative pedagogical solutions that are relevant to the demands of future education.

Among the various tools available, virtual laboratories (VLs) show significant potential in developing concrete dimensions of Self-Regulated Learning (SRL) skills. Several studies have indicated that the use of VLs can enhance students' independence in conducting practical tasks, enabling them to plan, implement, and complete laboratory activities autonomously through digital platforms (Alfarsi & Mohd Yusof, 2020). The inherent features of VLs allow students to learn at their own pace and according to their individual learning styles, thereby naturally supporting personalized and self-directed learning (Maksum & Saragih, 2020). This study aims to examine how virtual laboratories can be effectively utilized to strengthen vocational students' self-regulated learning skills through the structured application of the ADDIE development model.

The effective implementation of virtual laboratories to promote independent learning carries significant implications for the evolving role of teachers. This does not imply that teachers become irrelevant or obsolete; rather, their role undergoes a fundamental transformation. Teachers are no longer the sole source of knowledge or the primary conveyors of content. Instead, they take on new roles as learning experience designers, facilitators, and metacognitive guides within a technology-rich learning ecosystem.

Independent learning should not be misunderstood as learning in isolation without guidance. Students, particularly those at the elementary and secondary levels still require structured learning, clearly defined objectives, and scaffolding support (Hou & Lu, 2017). While virtual laboratories provide environments conducive to self-directed exploration, their pedagogical effectiveness greatly depends on how teachers design learning activities and integrate them into the broader instructional flow.

Teachers are expected to develop structured yet flexible student worksheets (LKS) that allow room for exploration (Ilyas & Pasandaran, 2019), select virtual lab platforms that align with specific learning objectives and student characteristics (May et al., 2023), and combine them with relevant active learning models (Zhang et al., 2014). The teacher’s role is also crucial in initiating student motivation, monitoring progress (many VL platforms offer student activity tracking), providing personalized feedback, and assisting students in navigating technical or conceptual challenges.

Moreover, the teacher's role shifts toward a more metacognitive function supporting students in explicitly developing their self-regulated learning skills. This includes guiding students in setting personal learning goals, selecting effective learning strategies, monitoring their own understanding, and reflecting on both the learning process and outcomes within the virtual lab context.

Thus, the success of virtual laboratories in fostering learner autonomy depends not only on technological sophistication, but also on the teacher’s capacity and readiness to orchestrate a supportive learning environment, guide student exploration, and nurture reflective practices. This calls for a reorientation of teacher professional development shifting the focus from mere content mastery to the mastery of technology-integrated pedagogical strategies and metacognitive scaffolding (Sui et al., 2024).

More than just a practical teaching tool, virtual laboratories (VLs) demonstrate strong potential as catalysts for developing essential 21st-century competencies particularly independent learning, or self-regulated learning (SRL) (Kolil & Achuthan, 2024). Numerous studies have consistently associated the use of VLs with increased student motivation, which serves as a crucial prerequisite for fostering learning autonomy. The inherent features of VLs, such as opportunities for self-directed exploration, unlimited repetition, immediate feedback, and a safe environment for experimentation create highly conducive conditions for students to practice key SRL skills, including planning, monitoring, and evaluating their own learning processes.

RESEARCH METHODOLOGY

This virtual laboratory was developed using the ADDIE development model which consists of 5 stages, namely: (1) Analysis, (2) Design, (3) Development, (4) Implementation, and (5) Evaluation (Branch & Varank, 2009; Krisna et al., 2024).

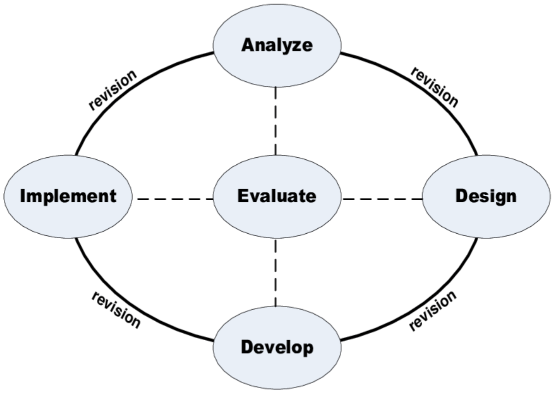

Figure 1. Addie Model (Branch & Varank, 2009; Krisna et al., 2024)

At the analysis stage, a needs analysis was conducted through observation and interviews at SMK Negeri 1 Tondano to gather information related to the problems experienced, so that both user needs and system requirements could be formulated. The next stage is the design phase, in which a virtual laboratory prototype was developed based on the results of the previous analysis, using flowcharts, menu structures, and storyboards as foundational elements for development. The third stage is development, where the virtual laboratory was built according to the design specifications. The fourth stage is implementation, in which the developed virtual laboratory was validated by two media experts and then tested in a limited classroom setting involving 60 students of SMK Negeri 1 Tondano, divided into two classes of 30 students each, to assess its usability. In this study, the independent variable is the use of a virtual laboratory based on the ADDIE model, while the dependent variables are students' learning motivation and independent learning (self-regulated learning) skills. These variables were measured using pre-test and post-test questionnaires as well as observations of student learning activities, in order to evaluate the impact of the virtual laboratory on the development of 21st-century competencies.

Data collection in this research was carried out by means of observation, interviews and using questionnaires for ISO 25010 tests and learning outcome tests. Observations and interviews were used in the analysis stage to obtain initial information regarding the future development of virtual laboratories. Meanwhile, the ISO 25010 standard is a standard in measuring the quality of software consisting of a quality in use model and a software product quality model (Mulyawan et al., 2021) and in the development of this virtual laboratory, usability testing and functional suitability testing were used. To measure the effectiveness of this virtual laboratory in improving students' independent learning abilities, learning outcome tests were used.

Table 1. Media Expert Test Outline Using Iso 25010

No	Variables	Indicator	Question Items	Questionnaire Number
1	Usability	Learnability	4	1 – 4
		Operability	4	5 – 8
		User Error Protection	3	9 – 11
		User Interface Aesthetics	3	12 – 14
		Satisfaction	3	15 – 17
2	Functional Suitability	Functional Completeness	3	18 – 20
		Functional Correlation	4	21 – 24
		Functional Appropriateness	3	25 - 27

Sources: The media expert test instrument was developed based on the ISO 25010 quality model, as supported by previous studies (Baul Canlas et al., 2021; für Normung, 2011; S. Pressman & R. Maxim, 2020; et al., 2016).

This research uses data analysis techniques in the form of descriptive statistics to describe data quantitatively based on a feasibility questionnaire with categories (Widoyoko, 2014) student trials. This virtual laboratory will be declared feasible to use if the average value of the media expert and students obtains a minimum value in the score range with the interpretation of "Feasible".

Table 2. Interpretation Scale Table

Score Range	Interpretation
MI + (1.8 x Ideal STDEV) to Maximum Score Value	Very Worth It
MI + (0.6 x Ideal STDEV) to MI + (1.8 x Ideal STDEV)	Worthy
MI – (0.6 x Ideal STDEV) to MI + (0.6 x Ideal STDEV)	Quite Decent
MI – (1.8 x Ideal STDEV) to MI – (0.6 x Ideal STDEV)	Not feasible
Minimum to MI Score Value – (1.8 x Ideal STDEV)	Totally Unworthy

Source : (Widoyoko, 2014)

Table 3. Assessment Category Criteria Table

No.	Score Range	Category
1	$\bar{X} > 109.2$	Very Worthy
2	$88.4 < \bar{X} \leq 109.2$	Eligible
3	$67.6 < \bar{X} \leq 88.4$	Fairly Decent
4	$46.8 < \bar{X} \leq 67.6$	Not Worthy
5	$\bar{X} \leq 46.8$	Totally Unfit

Source: Researcher's development, adapted from (Sugiyono, 2013; Widoyoko, 2014)

To find out how effective this virtual laboratory is in improving independent learning skills, inferential statistical analysis is used, preceded by a data normality test using the Kolmogorov-Smirnov Test, then a test is carried out to determine whether there are differences in the variables in the hypothesis using the t-test (Ridwan, 2012).

RESULTS AND DISCUSSION

The results of this study are virtual laboratories to improve students' independent learning abilities using the ADDIE model which is divided into 5 stages, namely analysis, design, development, implementation, and evaluation. This virtual laboratory was tested by media experts and 60 students of SMK Negeri 1 Tondano who were divided into 2 classes, each consisting of 30 students in a small class trial.

Analysis Stages

This initial stage is the foundation of developing a software including this virtual laboratory, at this stage the identification of needs, the purpose of developing the virtual laboratory, target users and obstacles that may occur in the development or when using the virtual laboratory. Needs analysis is obtained from observations and interviews conducted by exploring the problems that arise, namely the weak desire for independent learning of students due to the lack of media that supports independent learning, especially in the topic of computer assembly and students do not have computers that can be used as tools for practicing computer assembly. Meanwhile, to produce good computer assembly skills, students must practice often. In this stage, the learning objectives and content of the material that will be achieved and must be present in the development of the virtual laboratory are also formulated which can improve students' independent learning abilities. After the user needs analysis is obtained, it is continued with the analysis of system needs which is the technical basis for developing the virtual laboratory.

Design Stages

The results of the analysis of user needs and user requirements are the basis for creating a virtual laboratory design in the form of a virtual laboratory blueprint. The design is made in several stages, namely creating a virtual laboratory storyboard for all scenes and creating a flowchart that describes the user experience from start to finish. Then the user interface and user experience (UI/UX) are designed visually to be intuitive, attractive and easy to use so that they can improve independent learning abilities. In creating the UI/UX, the navigation structure, button layout, 3D component visualization, and interaction methods are considered so that they can be in accordance with user needs.

Development Stages

At this stage, the virtual laboratory is built by utilizing all the components and sets needed according to the blueprint design. The results of the development of the virtual laboratory for computer assembly can be seen in the picture.

Source: Researcher's Development Result (2024)

Figure 2. Development Outcome of the Virtual Laboratory for Computer Assembly Implementation Stages

The development of the virtual laboratory that has been completed will then be tested for feasibility by two media experts and 10 users consisting of 2 teachers and 8 students. The results of the media expert test can be seen in table 4 and the results of the trial for 10 users can be seen in table 5 below:

Table 4. Table of Media Expert Assessment Results

No.	Variables	Indicator	Score	Category
1	Usability	Learnability	110	Very Worthy
		Operability	101	Eligible
		User Error Protection	108.2	Eligible
		User Interface Aesthetics	114.8	Very Worthy
		Satisfaction	120.2	Very Worthy
2	Functional Suitability	Functional Completeness	109.2	Eligible
		Functional Correlation	108	Eligible
		Functional Appropriateness	109.2	Eligible
The final result			110,075	Very Worthy

Source: Researcher's Data Processing (2024)

The results of the feasibility test by 2 experts obtained a final score of 110,075 so that the virtual laboratory for computer assembly is Very Feasible for use.

Table 5. User Assessment Results Table

No.	Variables	Indicator	Score	Category
1	Usability	Learnability	107.8	Eligible
		Operability	121	Very Worthy
		User Error Protection	119	Very Worthy
		User Interface Aesthetics	126.2	Very Worthy
		Satisfaction	104.3	Eligible
2	Functional Suitability	Functional Completeness	109.7	Very Worthy
		Functional Correlation	99.4	Eligible
		Functional Appropriateness	107	Eligible
The final result			111.8	Very Worthy

Source: Researcher's Data Processing (2024)

The results of the feasibility test by 10 users consisting of 2 teachers and 8 students obtained a final score of 111.8 so that the virtual laboratory for computer assembly is Very Feasible for use.

After obtaining the results of the feasibility test from media experts and users, the virtual laboratory will then be tested in a small class trial involving 30 students to determine the effect of the virtual laboratory in improving students' independent learning abilities. The following are the results of the homogeneous test and the average results of the students' post-test on the computer assembly material.

Table 6. Homogenity Test Results

Levene Statistics	df1	df2	Sig.
.148	1	52	.703

Source: Researcher's Data Processing (2024)

Table 7. Students' Post-Test Results

	Class	N	Mean	Std. Deviation	Std. Error Mean
Posttest_Results	TKJ 1	30	62.18	16,178	3.013
	TKJ 2	30	41.33	13.204	2,497

Source: Researcher's Data Processing (2024)

Table 8. Results of independent samples test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Posttest_Results	Equal variances assumed	1.293	.231	3,879	56	.000	20,850	4,000	7.310	22.121
	Equal variances not assumed			3,789	54,281	.000	20,850	4.021	7.112	22.173

Source: Researcher's Data Processing (2024)

Based on the homogeneity test results shown in Table 6, the significance value was 0.703, which is greater than 0.05. This indicates that the two groups had similar baseline understanding of computer assembly concepts. Table 7 further reveals a difference in post-test scores between the Computer and Network Engineering Class 1 (Teknik Komputer dan Jaringan 1 / TKJ 1), which utilized a virtual laboratory, and Class 2 (TKJ 2), which did not. TKJ 1 achieved a higher average score of 62.18 compared to TKJ 2's 41.33. Table 8 supports this with a t-test result showing a significance value (2-tailed) of 0.000, which is less than 0.05, indicating a statistically significant difference. These findings demonstrate that the integration of virtual laboratories effectively enhances students' independent learning abilities.

Discussion

This study comprehensively examines the development and effectiveness of a virtual laboratory as an innovative learning medium aimed at enhancing independent learning skills among vocational high school students. The development of the virtual laboratory in this research methodically follows the ADDIE model, comprising the stages of Analysis, Design, Development, Implementation, and Evaluation (Branch & Varank, 2009; Molenda, 2015).

The choice of the ADDIE model is based on its proven advantages in the development of digital learning media. According to (Peterson, 2003), ADDIE offers a systematic framework that enables developers to accurately identify learning problems and design effective solutions. This aligns with the findings of (Gagné et al., 2005), who assert that the ADDIE approach facilitates the development of learning media that are responsive to learners' needs and specific instructional contexts.

Furthermore, ADDIE is deemed particularly suitable for vocational education contexts specifically in Computer and Network Engineering (Teknik Komputer dan Jaringan, or TKJ), due to its flexible and iterative structure. Unlike more rigid and linear models such as Dick and Carey or the Kemp Model, ADDIE supports adaptive development, making it more appropriate for the dynamic nature of technical skills training. This makes ADDIE highly relevant for the development of practical learning media that require continuous refinement based on field feedback and technological advancements (Branch & Varank, 2009).

Unlike previous studies that have primarily focused on instructional effectiveness, this research adds a new dimension by incorporating technical validation based on international standards (ISO 25010), thereby contributing to the development of media that are not only pedagogically sound but also meet quality criteria for software products. As such, this study positions itself as an extension of prior research, emphasizing the systematic integration of the ADDIE model with international software quality standards within the context of vocational education supported by virtual laboratories.

In the context of vocational learning, this study addresses the challenges of managing cognitive load in practical education, as emphasized (Clark et al., 2011). They highlight that effective instructional environments should minimize extraneous cognitive load while promoting germane processing through authentic and engaging tasks. Traditional vocational laboratories often face constraints such as limited equipment and high operational costs, which can hinder consistent access to hands-on learning. To bridge this gap, the virtual laboratory developed in this study offers an interactive, accessible learning environment that supports cognitive efficiency and enables students to engage in realistic simulations anytime and anywhere.

The feasibility of the virtual laboratory (VL) was rigorously evaluated using the international software quality standard ISO 25010, focusing on the dimensions of Usability and Functional Suitability. The use of ISO 25010 is consistent with usability principles emphasized by (Nielsen & Budiu, 2013) in Mobile Usability, particularly in ensuring that mobile-based learning tools are effective, user-friendly, and contextually appropriate for learners.

A detailed analysis of the usability indicators revealed that aspects such as Learnability, User Interface Aesthetics, and Satisfaction achieved a "Highly Feasible" rating. This is significant, as prior studies have consistently shown that ease of use, aesthetic design, and satisfying user experiences are strong predictors of technology acceptance and serve as key motivators for initial engagement with learning media (Davis, 1989; Venkatesh et al., 2003).

(Hwang & Chang, 2011) in Computers & Education confirmed that high usability in digital learning media significantly contributes to increased student engagement and persistence in independent study. The intrinsic motivation generated from these positive experiences provides a crucial foundation for learners to further engage in self-directed exploration supported by virtual laboratories.

Other usability indicators (Operability, User Error Protection) and all Functional Suitability indicators (Completeness, Correctness, Appropriateness) received a "Feasible" rating. While these results still meet the minimum standards of feasibility, they also suggest potential areas for improvement in future development iterations, such as streamlining operational flows or adding specific functional features.

These findings are consistent with the iterative design approach advocated by (Preece et al., 1994), who argue that the development of digital learning media requires continuous cycles of evaluation and refinement to achieve optimal quality. A similar approach is used by (Alessi & Trollip, 2000) in multimedia learning development, which emphasizes ongoing improvement based on user feedback.

Overall, the media expert validation strongly confirms that the developed VL meets high-quality standards and is ready for implementation in real-world learning environments. This rigorous testing process parallels that used in the development of other platforms like Arutala, which also employed Black Box testing, usability assessments, and expert validation.

This study contributes to the body of knowledge in digital learning media development through the systematic integration of ISO 25010 standards with the ADDIE model in vocational education an area still underexplored in the literature (Anderson & Krathwohl, 2001; Bloom et al., 1964). It also reinforces the argument for user-centered design in the development of virtual laboratories, as advocated by (Norman, 2013) in The Design of Everyday Things.

The results of the technical validation provide a strong foundation for exploring the impact of virtual laboratories on students' independent learning. High usability especially in terms of Learnability and Interface Aesthetics is a key prerequisite for the effectiveness of VL-based learning. As stated by (Sweller, 1994; Sweller et al., 2011) in Cognitive Load Theory, intuitive and easy-to-learn interfaces reduce extraneous cognitive load, allowing students to focus on conceptual understanding rather than grappling with technological complexity. This supports (Davis, 1989) finding that perceived ease of use is a determinant factor in the adoption and sustained use of educational technologies.

The improvement in learning outcomes can thus be interpreted as a strong indicator of enhanced independent learning capability. Numerous studies have consistently shown that virtual laboratories, including specific platforms such as PhET, popular in Indonesia are effective in improving students' conceptual understanding. This improvement is often attributed to the unique ability of virtual labs to visualize abstract concepts or complex processes, which are difficult to convey through traditional teaching methods.

Moreover, the positive correlation between the use of virtual laboratories and increased student motivation has been well documented in various studies (Fang et al., 2024; Li & Keller, 2018). The underlying mechanism for this motivational boost is often explained through Keller's ARCS model (Attention, Relevance, Confidence, Satisfaction), introduced in 1984. The ARCS model is widely recognized in educational research and practice, with growing interest in applying it within technology-enhanced learning environments. Virtual laboratories are particularly effective at capturing students' Attention through engaging visuals and interactivity. The Relevance of learning materials increases as students observe the real-world applications of theoretical concepts. Research has shown that variables such as scaffolding, real-time feedback, success rates, and time spent on tasks, and learning outcomes are positively correlated with the four motivational components of the ARCS model.

Successful experimentation and concept mastery enhance students' Confidence and lead to a greater sense of Satisfaction (Laurens-Arredondo, 2022). Similar increases in motivation have also been observed with other interactive tools such as augmented reality and digital learning technologies, further underscoring the role of interactivity and visual elements in stimulating learning interest.

Most importantly, the inherent features of virtual laboratories directly support the development of independent learning. The ability to explore freely without fear of damaging equipment fosters initiative and curiosity. Unlimited opportunities to repeat experiments promote self-paced learning, which lies at the heart of autonomous learning. Immediate feedback enables students to make corrections and reflect independently. Studies indicate that virtual labs significantly enhance metacognitive self-regulation, effort regulation, peer learning, and overall self-regulated learning (SRL) to a greater extent than physical laboratories. Virtual labs have been shown to make learning more engaging, exciting, and meaningful, while also improving academic performance. Although research specifically examining the impact of virtual labs on learner autonomy remains limited, systematic reviews suggest that well-structured virtual lab environments can support key SRL phases such as forethought/planning, self-monitoring, and self-evaluation (Al-Duhani et al., 2024). The heightened motivation induced by virtual labs likely encourages students to actively engage with autonomy-supporting features, ultimately contributing to improved learning outcomes.

The advantages of virtual laboratories in terms of accessibility, cost-efficiency, time and location flexibility, and safety make them a practical solution to the limitations posed by physical labs and inadequate infrastructure, which remain persistent challenges in many Indonesian schools. Platforms such as the Virtual Lab from Rumah Belajar by the Ministry of Education, or free resources like PhET simulations, represent ongoing efforts to provide affordable virtual lab access. In the context of Indonesia's ongoing educational transformation toward more autonomous and technology-integrated learning, virtual laboratories hold great potential as innovative pedagogical tools. However, their successful implementation still depends on teacher readiness and infrastructural support.

CONCLUSION

The feasibility tests conducted by both media experts and users indicate that the developed virtual laboratory is classified as "highly feasible." Following this validation, the virtual lab was implemented in a small-scale classroom trial involving two student groups. Post-test results showed a statistically significant difference in favor of the experimental group that used the virtual laboratory, suggesting that the virtual lab has the potential to enhance students' independent learning abilities, particularly in the area of computer assembly. In this study, independent learning ability refers to students' readiness and motivation to engage in learning autonomously, as evidenced by improved conceptual understanding and performance on post-tests following the use of the virtual lab. These findings align with previous research indicating that virtual environments can foster self-directed exploration and provide opportunities for repeated practice. Nevertheless, while the results are promising, several limitations must be acknowledged. The study was conducted with a relatively small sample (60 students), over a short duration, and within a single vocational school. These factors limit the generalizability and the long-term implications of the findings. Therefore, further research involving larger and more diverse populations across a range of instructional settings is recommended to better assess the long-term effectiveness and scalability of virtual laboratories in vocational education.■

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