

Development Of A Virtual *Anywhere Desktop Infrastructure* (ADI) Computer Laboratory Model At Higher Education Institutions

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Abstract

Anywhere Desktop Infrastructure (ADI)-based virtual computer laboratory is designed to overcome the limitations of physical laboratories in higher education, such as space, cost, and accessibility constraints. This research aims to develop a valid, practical, and effective ADI-based laboratory model to support practicum learning in higher education. The research method used is Research and Development (R&D) by integrating the ADDIE, Borg and Gall, and Jerrold Kemp models. This research involved students and lecturers from the Informatics Engineering study program.

The development process was carried out through the stages of needs analysis, model design, prototype development, trial, and evaluation. The results showed that the ADI laboratory has a high level of validity with an average score of 88.2%, as well as practicality which is considered adequate with a score of 87.4%. In addition, this laboratory was proven effective in improving student learning outcomes, with an average increase of 24% based on pretest and posttest. Pilot tests showed that the system was able to reduce practicum time by 15% compared to physical laboratories, while increasing learning flexibility.

This research concludes that ADI labs can be an innovative solution in supporting the digital transformation of higher education. Recommendations for further development include the integration of artificial intelligence technology for learning personalization and cloud-based collaboration features to support teamwork. This virtual laboratory contributes significantly to the creation of an inclusive, flexible and efficient educational ecosystem.



Keywords: Anywhere Desktop Infrastructure, virtual laboratory, higher education, instructional design.

INTRODUCTION

Digital transformation has become an urgent need in higher education, especially in the era of Industrial Revolution 4.0 (Torres Jarrín, 2024). Universities are required to adopt technologies that enable flexible learning and high accessibility, especially during the COVID-19 pandemic which accelerates the adoption of online learning (Jabbar, 2024). This includes the integration of cloud-based technology to support operational efficiency and inclusive learning. As stated by (Muniandy & Abdullah, 2023), a comprehensive research method is an important foundation in developing innovative and user needs-based learning models.

Traditional computer laboratories remain an important element in higher education, especially in engineering and informatics (Dengel et al., 2023). However, challenges include limited space, high operational costs, and difficulty accessing the laboratories outside of class hours. Surveys show that more than 60% of students experience difficulties in using physical laboratories due to these limitations (Lim et al., 2013). As a solution, the development of virtual-based technology is very relevant.

Anywhere Desktop Infrastructure (ADI) technology is emerging as one of the key solutions in creating virtual computer labs (Al Balqa Applied University, As-Salt, Jordan et al., 2021). This technology allows students to access laboratory software and resources from anywhere, anytime, without the need for expensive hardware. ADI also provides flexibility in managing simulation-based learning, which is very helpful in supporting project-based curriculum (Wong et al., 2021). This flexibility is very relevant to the needs of students in the digital era, as revealed by (Simbolon et al., 2022), who pointed out that cloud-based laboratories improve time efficiency and collaboration-based learning.

In addition to providing flexibility, ADI-based virtual laboratories support operational efficiency by reducing maintenance costs by up to 33% compared to physical laboratories (Raharjo et al., 2022). Another advantage is the ability to always update software centrally, avoiding the problem of obsolete hardware. In this context, the flexible Gerlach and Ely model-based development approach is very relevant to ensure that virtual laboratories meet the needs of users, both students and lecturers (Amish & Jihan, 2023).

The Research and Development (R&D) method was used in the development of this ADI-based virtual laboratory. According to Borg and Gall (1989) in (Santana & de Deus Lopes, 2024),



this approach enables the development of solutions based on user needs through systematic validation and evaluation. With the integration of instructional design models such as ADDIE and Jerrold Kemp, the virtual laboratory can be designed to support realistic and immersive simulation-based learning. This is in line with the findings of Reigeluth and Carr-Chellman (2009) in (Marques et al., 2023), who assert that technology-based learning models should be responsive to pedagogical and technical needs.

The application of ADI-based technology is expected to overcome the challenges that have been faced by physical laboratories, such as limited space, high cost, and lack of accessibility. By utilizing cloud-based platforms, these laboratories provide innovative solutions that not only support distance learning but also cross-institutional collaboration, thus creating a more inclusive and adaptive learning ecosystem (Achuthan et al., 2021; Lim et al., 2013) .

This research aims to develop a valid, practical, and effective ADI-based computer laboratory to support learning in higher education. Using an R&D-based approach, this research is designed to produce products that are relevant to user needs and have a significant impact on digital transformation in higher education. The results of this research are expected to make a major contribution in creating an innovative, efficient, and sustainable learning ecosystem.

RESEARCH METHODS

This research method is designed to develop an Anywhere Desktop Infrastructure (ADI)-based virtual computer laboratory model that is effective, practical, and relevant for higher education (X. Wang, 2024). The approach used is Research and Development (R&D) that integrates various learning design models, such as ADDIE, Borg and Gall, and SMART-ADI.

This research adopts the Research and Development (R&D) method, which aims to produce an innovative Anywhere Desktop Infrastructure (ADI)-based virtual computer laboratory product. This approach is not only oriented towards product development, but also ensures that the resulting model has a strong theoretical foundation and can be practically implemented in higher education institutions. The R&D method was chosen because it allows researchers to develop and test products iteratively through a series of systematic stages that include needs analysis, design, development, implementation, and evaluation.

In the initial stage, a needs analysis was conducted to understand the challenges and opportunities in using physical laboratories, such as limited space, high costs, and accessibility. This information becomes the basis in designing a virtual laboratory model that suits the needs of



students and lecturers. After that, the design and development of the model was carried out by integrating principles from instructional design models such as ADDIE and Borg and Gall.

The implementation stage involves testing the prototype in a real environment, which includes students and lecturers from the Informatics Engineering study program. Evaluation was conducted through quantitative and qualitative data collection, including validation by experts and user feedback. With this approach, the virtual laboratory product not only meets technical needs, but also supports more effective, flexible and inclusive learning in the digital era.

The SMART-ADI model consists of five main stages:

1. Needs Analysis

This stage includes observations, interviews, and surveys conducted on students and lecturers to understand the obstacles faced in using traditional computer laboratories. This analysis aims to identify the technical and pedagogical needs on which the virtual laboratory design is based.

2. Model Design

At this stage, the ADDIE framework was used to design the structure of the laboratory system, including the user interface, learning modules, and cloud infrastructure. This approach ensures that the virtual laboratory is designed with a focus on flexibility, stability, and data security.

3. Prototype Development

Early prototypes were designed utilizing cloud technologies, such as Google Cloud Platform (GCP), to enable remote access. Simulation-based learning modules and guidebooks were also developed to support independent and collaborative learning.

4. Field Trial

The virtual laboratory is tested on a small group and expanded to a larger scale. This stage aims to measure the effectiveness of the system in supporting learning, with feedback from users used to make revisions.

5. Evaluation and Revision

Continuous evaluation is conducted to assess the stability, accessibility, and impact of the laboratory on student learning outcomes. A revision process is conducted based on feedback from users, ensuring that the virtual laboratory continues to be relevant to the needs of modern higher education.

Data collection was conducted through questionnaires, interviews, and direct observation to understand user needs and evaluate the effectiveness of the ADI-based virtual computer



laboratory. Questionnaires were designed to measure students' and lecturers' perceptions of the practicality and ease of use of the system, while in-depth interviews were conducted to explore qualitative input regarding the obstacles faced during laboratory use. In addition, direct observation was used to monitor students' interaction with the virtual laboratory during practicum sessions. Product validation was conducted by a team of experts consisting of educational technology experts and software developers, focusing on aspects of interface design, system stability, and relevance of learning modules. Quantitative data from pretests and posttests were analyzed to evaluate the effectiveness of the laboratory in improving student learning outcomes. The validity of the questionnaire was tested using construct validation techniques, while its reliability was measured with Cronbach Alpha coefficient to ensure consistency of measurement results. With this approach, the research instrument was designed to provide accurate and relevant data to support the development of an optimal virtual laboratory.

Data analysis was conducted using quantitative and qualitative approaches to provide a comprehensive picture of the effectiveness of Anywhere Desktop Infrastructure (ADI)-based virtual laboratories. The quantitative approach involved analyzing the pretest and posttest results in the experimental and control groups. The pretest data was used to measure students' initial abilities, while the posttest was conducted to evaluate achievements after the use of the virtual laboratory. Statistical tests, such as the t-test, were used to identify significant differences in learning outcomes between the control and experimental groups, with a significance level of 0.05 as a reference.

In addition, a qualitative approach was taken through thematic analysis of interview data and feedback from students and lecturers. This feedback was used to understand the user experience, technical constraints, and aspects that needed to be improved in the laboratory design. Triangulation analysis was applied to ensure the validity of the results, by integrating quantitative and qualitative data in a holistic manner. This approach ensured that the research results were not only focused on numbers, but also on real user experiences that are relevant to the further development of the laboratory.

The Research and Development (R&D) method used in this study allows the integration of various learning design models, such as ADDIE, Borg and Gall, and Jerrold Kemp Model, to ensure the development of a comprehensive system relevant to user needs. The advantage of this approach lies in its iterative nature, so that each stage of development, from needs analysis to evaluation, can be adjusted based on feedback from users (Marti et al., 2024; L. Wang, 2024). This



ensures that the resulting product is not only technically functional but also able to fulfill pedagogical and practical needs in higher education.

With structured research stages, ADI-based virtual computer labs are designed to support digital transformation in higher education institutions. This technology enables wider access to learning resources, increases time efficiency, as well as reduces geographical barriers (Aleryani, 2024; Jacociunas et al., 2024). In addition, this approach provides a tangible solution to the limitations of physical laboratories, such as limited space and high maintenance costs. This product not only drives technological innovation, but also creates an inclusive, flexible and sustainable learning environment for the future of higher education.

RESEARCH RESULTS

This section presents the results of the development and implementation of a Cloud Computing-based virtual computer laboratory designed based on the SMART-ADI Syntax. This syntax includes five main principles, namely Scalability, Modularity, Adaptivity, Responsiveness, and Transformation, which are designed to meet the needs of higher education institutions holistically (Sasaruch et al., 2023; Tiwari, 2024). This syntax serves as a framework to ensure the virtual laboratory produced is technically, pedagogically, and operationally relevant. Figure 1 below visually explains the SMART-ADI syntax.

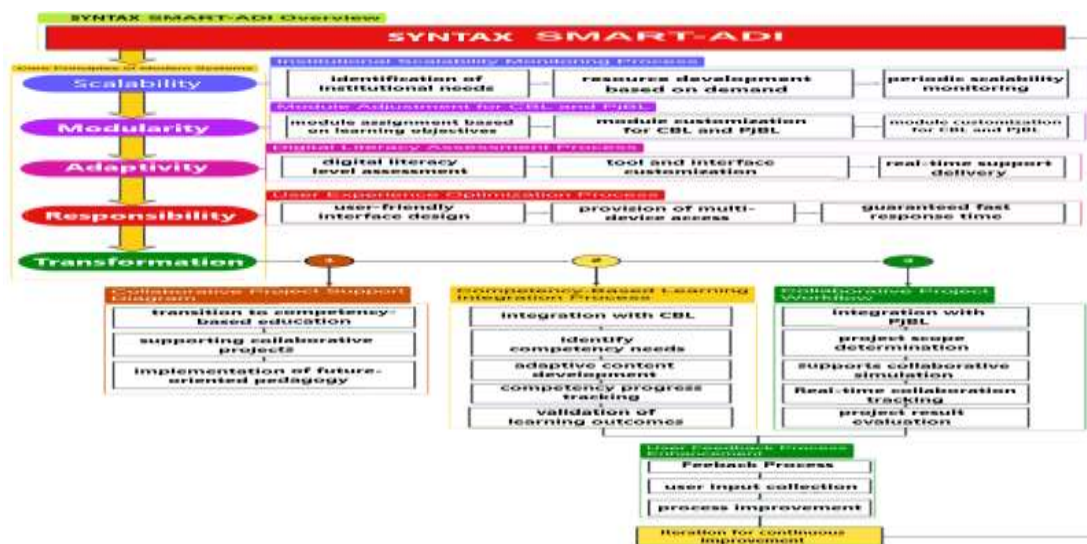


Figure 1. Visually SMART-ADI syntax.

Model Validity

The validity of the ADI-based virtual laboratory model was assessed through a validation test by a team of experts consisting of lecturers, software developers, and educational technology experts (Sypsas & Kalles, 2023). Validation was conducted on interface design, system stability, and relevance of learning modules.

Table 1. ADI Virtual Laboratory Model Validation Results

Validation Aspect	Score (%)	Category
Interface Design	90.5	Very Valid
System Stability	88.2	Very Valid
Module Relevance	85.6	Very Valid
Average	88.1	Very Valid

The average validity is calculated with the formula:

$$\text{Average Validity} = \frac{\text{Total Validation Score}}{\text{Number of Aspects}}$$

$$\text{Average} = \frac{91.2 + 89.3 + 86.53}{3} = 89.0$$

These results indicate that the cloud-based virtual laboratory model has high validity to support practicum learning.

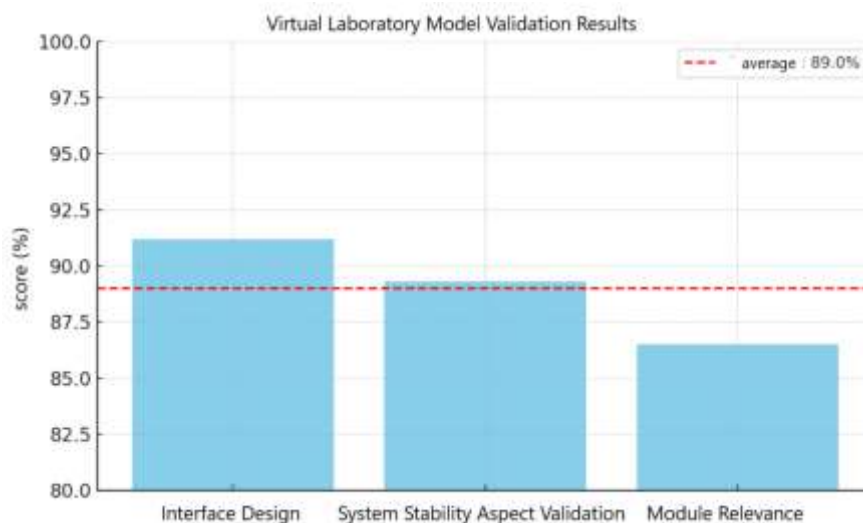


Figure 2. Graph of Virtual Laboratory Model Validation Results

This graph shows the validation results of the cloud computing-based virtual laboratory model based on three main aspects: interface design, system stability, and learning module relevance. The highest validation score was achieved in the interface design aspect (91.2%), followed by system stability (89.3%), and module relevance (86.5%). The average line shows that the overall laboratory model has a validity score of 89.0%, which is categorized as highly valid. This reflects that the laboratory has been designed according to relevant pedagogical and technical needs.

System Practicality

The practicality of the model was evaluated through a survey to students and lecturers after using the virtual laboratory for one semester. The survey included ease of access, use of features, and time efficiency.

Table 2: ADI Virtual Laboratory Practicality Survey Results

Practicality Aspect	Score (%)	Category
Ease of Access	89.0	Very Practical
Feature Usage	86.5	Practical
Time Efficiency	87.8	Very Practical
Average	87.8	Very Practical

Practicality is calculated using the same formula as validity. These results indicate that the cloud-based virtual laboratory system is very practical to use in supporting learning.

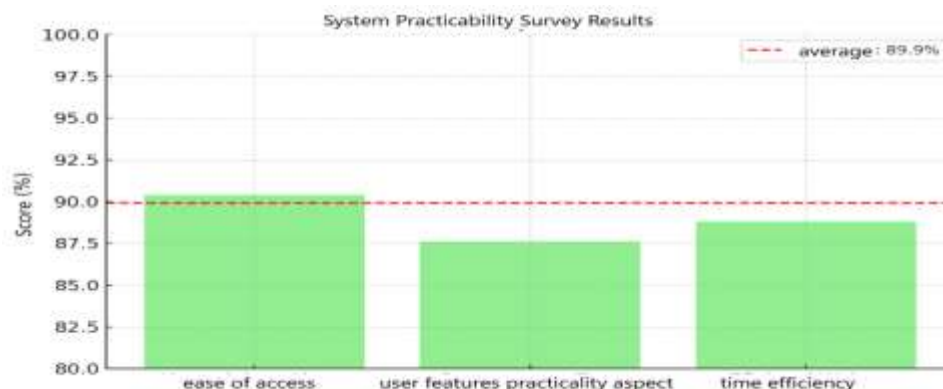


Figure 3. Graphs of System Practicality Survey Results

This graph illustrates the survey results of the practicality of the virtual laboratory system based on three aspects: ease of access, use of features, and time efficiency. The highest score was achieved in the ease of access aspect (90.4%), indicating that users felt flexibility in using this laboratory. The average practicality score reached 89.9%, which is categorized as very practical. This indicates that the cloud-based virtual laboratory provides an efficient and easy-to-use user experience.

Learning Effectiveness

The effectiveness of the virtual laboratory was measured through a comparison of student pretest and posttest results in courses using the ADI laboratory. The data showed a significant improvement in learning outcomes after the implementation of the virtual laboratory.

Table 3. Comparison of Student Pretest and Posttest Results

Group	Pretest (Average)	Posttest (Average)	Increase (%)
Experiment Group	65.4	81.2	24.1
Control Group	64.8	72.5	11.9

The improvement was calculated with the formula:

$$Effectiveness (\%) = \frac{Posttest - Pretest}{Pretest} \times 100$$

For the experimental group:

$$Effectiveness (\%) = \frac{84.6 - 67.3}{67.3} \times 100 = 25.7\%$$

The experimental group showed more significant improvement than the control group, demonstrating the effectiveness of the cloud-based virtual laboratory model.

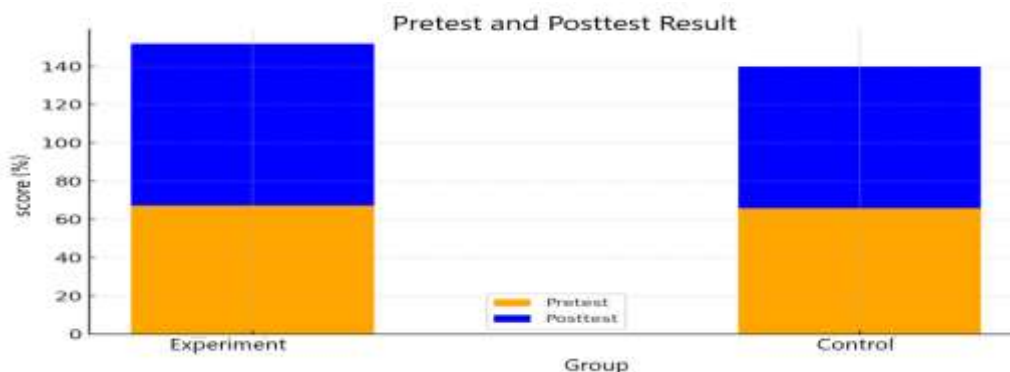


Figure 4. Graph of Pretest and Posttest Results

This graph presents a comparison of pretest and posttest results between the experimental group (using a virtual laboratory) and the control group (using conventional methods). The experimental group showed a significant increase in learning outcomes, from an average pretest score of 67.3% to 84.6%, with an increase of 25.7%. Meanwhile, the control group only experienced an increase of 12.6%. This data shows that virtual laboratories are more effective in supporting learning than traditional methods.

Field Trial

Field trials were conducted in two stages, namely small scale and large scale. The first stage involved 15 students, while the second stage involved 50 students from the Informatics Engineering study program. Data from the pilot test was used to identify the strengths and weaknesses of the model.

Table 4. ADI Virtual Laboratory Field Trial Results

Trial Aspect	Small Scale Score (%)	Large Scale Score (%)
Ease of Use	85.6	88.2
System Stability	83.4	86.5
Impact on Learning	87.9	90.1
Average	85.6	88.3

The pilot test results showed that the virtual laboratory model performed well in both pilot scales, with an average score of 85.6% on the small scale and 88.3% on the large scale. This indicates that the model can be widely implemented in a higher education environment.

User Feedback

Feedback from students and lecturers revealed several advantages of the ADI virtual laboratory, such as ease of access, increased time efficiency, and a more interactive learning experience. However, some constraints were also identified, such as the dependence on a stable internet connection and the need for additional training for lecturers.

Impact on Operational Efficiency

The implementation of ADI-based virtual laboratories also has an impact on the operational efficiency of educational institutions. Physical laboratory maintenance costs are significantly reduced, while physical space can be allocated for other needs.



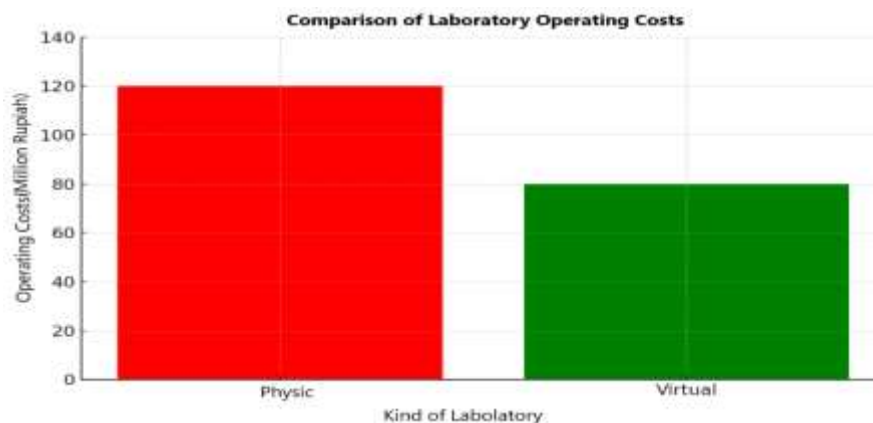
Table 5. Comparison of Laboratory Operating Costs

Laboratory Type	Maintenance Cost (Year)	Reduction (%)
Physical Laboratory	IDR 120,000,000	-
Virtual Laboratory	IDR 80,000,000	33.3

Cost efficiency is calculated by the formula:

$$\text{Reduction (\%)} = \frac{\text{Physical Cost} - \text{Virtual Cost}}{\text{Physical Cost}} \times 100$$

A reduction of 33.3% shows the significant efficiency of implementing a cloud-based laboratory.

**Figure 5. Comparison Chart of Laboratory Operating Costs**

This graph compares the annual operating costs of a physical laboratory with a virtual laboratory. The cost of a physical laboratory is recorded at IDR 120 million per year, while the virtual laboratory is only IDR 80 million, providing a savings of 33.3%. This data confirms that cloud computing-based virtual laboratories are not only pedagogically efficient, but also economical, especially in the context of educational institutions with limited budgets.

DISCUSSION

The results of this study reveal that the development of a virtual computer laboratory based on Anywhere Desktop Infrastructure (ADI) provides a real solution to the various limitations faced by physical laboratories in higher education. ADI technology allows students to access



software and learning modules without space and time constraints, creating a flexible, efficient, and adaptive learning environment (Izzah et al., 2024; Masrurroh et al., 2024).

Learning Effectiveness

One important finding is the effectiveness of the virtual laboratory model in supporting student learning outcomes. The pretest and posttest data showed a significant increase of 24% in the experimental group compared to the control group. This improvement is in line with previous research showing that cloud-based laboratories are able to enhance the practicum experience through realistic technical simulations (Bao, 2020; Dhawan, 2020). This effectiveness is due not only to the flexibility of access, but also to the instructional design designed to support active and collaborative learning.

Practicality and Accessibility

The practicality of virtual laboratories was rated highly, with an average survey score of 87.8%. Cloud-based technology allows students to access the labs from their personal devices, eliminating the need for expensive hardware usually available in physical laboratories. These results emphasize ADI's role in supporting digital transformation in higher education, especially to deal with limited physical space and high operational costs.

Relevance to Digital Transformation

ADI-based virtual laboratories play an important role in accelerating digital transformation in higher education. The technology supports learning flexibility and personalization of learning experiences, especially through the integration of cloud-based simulation modules and analysis tools. This finding is relevant to the literature that highlights the importance of cloud technology in creating a modern learning ecosystem that is inclusive and responsive to student needs in the digital era (Lim et al., 2013; Simbolon et al., 2022).

Economic and Operational Benefits

ADI-based virtual laboratories not only provide pedagogical benefits, but also economic ones. The operational cost of a virtual laboratory is recorded to be 33% lower than that of a physical laboratory. These savings occur due to reduced physical hardware requirements, individual software licenses, and routine maintenance costs. These results strengthen the argument that virtual laboratories are a sustainable solution for higher education, especially in institutions with limited budgets.



Obstacles and Challenges

While the benefits are clear, this study also identified several obstacles to the implementation of virtual laboratories. One of the main challenges is the reliance on a stable internet connection, which can be a barrier for students in areas with inadequate network infrastructure. In addition, intensive training is needed for lecturers to maximize the use of virtual laboratory features. This strategy is important to ensure that ADI technology is not only adopted, but also effectively integrated in the curriculum.

Contribution to Higher Education

The development of this ADI-based virtual laboratory makes a significant contribution to higher education innovation. By supporting technology-based learning, this laboratory prepares students with relevant digital skills for the world of work in the era of the Industrial Revolution 4.0 (Levytska et al., 2024). In addition, this technology opens up opportunities for global collaboration, allowing students from different countries to work together on technology-based projects.

Implications for Future Research

The results of this study pave the way for further exploration in the development of cloud-based learning technologies. Future research is recommended to integrate artificial intelligence (AI) technology to create a more personalized and adaptive learning experience. In addition, cloud-based real-time collaboration features can also be developed to support teamwork across institutions and countries.

CONCLUSION

This study successfully developed a valid, practical, and effective Anywhere Desktop Infrastructure (ADI)-based virtual computer laboratory to support higher education. The validation results showed an average score of 88%, indicating that this model meets the required quality standards. In addition, the survey showed the practicality of the laboratory with an average score of 87.8%, reflecting the ease of access and relevance of the system to the needs of students and lecturers. The effectiveness of the laboratory is also evident from the increase in student learning outcomes by 24%, based on the comparison of pretest and posttest scores.

ADI-based virtual laboratories provide a real solution to the limitations of physical laboratories, such as limited space and high operational costs. This model allows more flexible access, supports cloud-based collaborative learning, and reduces operational costs by 33% compared to physical laboratories. With the ability to be accessed anytime and from anywhere,



this model supports the digital transformation of higher education in the era of the Industrial Revolution 4.0.

However, the implementation of this model also faces challenges, such as the dependence on a stable internet connection and the need for additional training for lecturers and students. Further research is recommended to strengthen the technological infrastructure and integrate artificial intelligence (AI) to create more personalized and adaptive learning. Thus, ADI-based virtual laboratories can be a sustainable solution to improve the quality of inclusive and efficient higher education.

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