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Development of a remote physics laboratory to support equitable access to education

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ABSTRACT

Economic disparities and variations in geographical conditions in Indonesia exacerbate access to physics laboratories. Therefore, innovative solutions such as remote physics laboratories are needed to bridge this gap and provide more equitable access to students across the region, regardless of economic or geographical conditions. To overcome this, this research aims to develop a remote physics laboratory for equitable access to quality physics experiments. This research includes 4D model development research. The research subjects involved five students for the functionality test, 84 people for the user test, and ten media experts to assess the feasibility of the product. The instruments used include functionality test instruments, media expert assessments, and usefulness, satisfaction, and ease of use (USE) questionnaires. Tool functionality data and media expert validation were analyzed using the Aiken V technique. At the same time, the level of user acceptance was examined through a combination of Wright maps and logit item values. This development resulted in a remote physics experiment architecture and device with a good functionality assessment index. The assessment by media experts showed high validity. The level of user acceptance is classified in the medium to high category. Thus, the developed R-PhyLab has the potential to be an effective medium in equalizing access to quality physics laboratories in educational institutions that face economic limitations and unfavorable geographical conditions.

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1. INTRODUCTION

Differences in community economic levels and geographical conditions are determinants of education inequality [1]. The diverse economic level of the community is the main factor triggering inequality in the education sector [2]. Significant economic differences lead to unequal access to quality education. Inequality in education has broad and severe impacts on individuals and society [3]. Individuals who are marginalized from access to quality education will likely need help reaching their full potential and obtaining equal economic opportunities [4].

The diverse geographical conditions in various parts of Indonesia further widen inequalities in the education sector. Remote or isolated areas often need help in providing adequate education to students. Long distances from city centers and a lack of adequate transport infrastructure make it difficult for students in these areas to access quality schools [5]. As a result, many students in these areas are hindered from pursuing an education equal to that of students in urban areas. Therefore, the different geographical conditions in each region are crucial factors that contribute to educational inequality [6], making it difficult to provide equal educational opportunities for all Indonesian students. However, the government has made several efforts to reduce educational inequality in various regions of Indonesia.

In physics, students also feel inequality when conducting experiments because most campuses in various parts of Indonesia have inadequate educational infrastructure. Adequate infrastructure is mostly concentrated in large and developed cities. Physics education is identified with experiments, but the high price of experimental equipment and materials is an obstacle. Expensive experimental equipment requires maintenance that is not easy and cheap. Therefore, providing standardized laboratories on every campus requires a collective effort from various parties. Lack of access to laboratories can hinder students' learning experience [7]–[9]. Physical laboratories are often necessary for practical experiments and demonstrations that cannot be done effectively through traditional online learning. This can reduce students' practical understanding of physics subjects.

The government has tried to equalize internet access in various regions of Indonesia, including affirmative regions. Almost all regions given special attention by the government already have adequate internet networks. This opportunity must be utilized to bring a sense of justice to accessing education and minimize societal inequality. In distance learning, technology is the key to successfully bridging the interaction between teachers and learners [10], [11].

One of the efforts that can be made is to present a central laboratory that can be accessed by all groups remotely. Students from low economic backgrounds can access physics experiments using internet facilities like students from established economic backgrounds. Campuses in remote areas with inadequate infrastructure can easily access physics experiments. So that Indonesia's unique geographical conditions are no longer a problem. Campuses in remote or poor areas can conduct joint experiments across institutions [12], [13]. These campuses can skip procuring expensive laboratory equipment, complicated maintenance, and providing trained laboratory personnel. So, presenting a remote physics laboratory is one of the right solutions to create equal access to physics experiments throughout Indonesia.

Many researchers have conducted the development and implementation of various types of laboratories. Starting from practical (traditional) laboratories [14], virtual laboratories [15]–[17] to remote laboratories [18]. Traditional laboratories provide direct experience to students in conducting experiments and labs but are limited by space and equipment limitations. Meanwhile, virtual and remote laboratories can provide access anytime and anywhere, thus personalizing experiments and transcending physical boundaries [19], [20].

Virtual and remote laboratories have recently gained momentum in research due to advances in technology and network communication. Virtual and remote laboratories offer unique opportunities for students [21], [22]. Remote students can apply their acquired knowledge and conduct experiments like on-campus students without the need to be physically in the laboratory [12]. Virtual laboratories provide a safe and accessible environment for students [23]. However, the complexity of real-life situations is difficult to replicate in virtual environments and is usually ignored in theory. On the other hand, remote laboratories still illustrate the complexity of real-life situations.

Remote physics laboratories have been developed before [24]. The remote physics laboratory on Planck's constant is an innovative platform that allows students to measure and understand one of the fundamental constants of physics, Planck's constant (h). Planck's constant is fundamental in quantum phenomena such as the photoelectric effect. Through an online interface, users can remotely access and control experiments. The platform provides an interactive and immersive experience in learning quantum concepts, expanding access to physics experiments that may not be accessible locally. Therefore, this research aims to develop a remote physics laboratory apparatus on Planck's constant. Thus, the research questions are: i) Does the developed R-PhyLab have good functionality?; ii) Does R-PhyLab have good quality according to media experts?; and iii) Is R-PhyLab acceptable to potential users?

2. METHOD

2.1. Type of research and research procedures

This type of research is included in development research (research and development). The development model used is the define, design, develop, and disseminate (4D) model. The product developed is an experimental apparatus for R-PhyLab on Planck's constant (PC R-PhyLab). The development procedure follows the flowchart shown in Figure 1.

2.2. Research respondents

Based on the development procedure that has been carried out, five students were involved in the functionality test stage of PC R-PhyLab. Respondents of the functionality test stage were selected through a purposive sampling technique, namely those who have taken the experimental physics course [25]. A total of 10 physics education lecturers acted as media experts to assess the feasibility of the tool from the media aspect. Media experts were selected based on the inclusion criteria: i) physics education lecturers who focus on experimental physics; ii) have a minimum degree of master of physics education; iii) have a minimum teaching experience of 3 years; and iv) have the ability to evaluate learning instruments. The exclusion criteria are: i) have no experience in developing physics experimental tools; ii) not competent in the field of educational technology; and iii) not willing to be a validator. To obtain data stability with an accuracy of 0.5 logits and a confidence level of 95%, a sample size of 64-144 people is recommended [26]. Therefore, 84 physics education students involved in the user acceptance test met the requirements. During the user test, respondents were selected using a purposive sampling technique: students from three partner universities who had taken the experimental physics course.

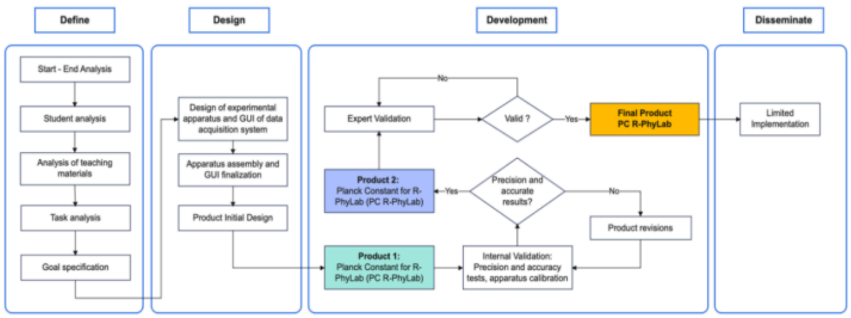

Figure 1. Flowchart of product development procedure design

2.3. Research instruments

Three types of instruments were used to assess the quality of the developed apparatus. The functionality test instrument for potential users consists of 21 items spread over six aspects, namely: technical, user experience (UX), pedagogical, functionality, environmental use, and economic and social aspects. The media expert assessment instrument consists of 22 items spread over eight aspects: user interface, multimedia quality, technology and performance, accessibility, experimentation functionality, user support, integration and collaboration, and user evaluation and feedback. Usefulness, satisfaction, and ease of use (USE) questionnaire to evaluate the level of user acceptance. The functionality test instrument for prospective users and the media expert assessment instrument have been agreed upon and declared feasible by three physics learning media experts. USE questionnaire was adapted from Lund [27].

2.4. Data analysis techniques

Potential user functionality tests and media expert validation were analyzed using the Aiken V technique. This technique makes it possible to obtain agreement from several raters. User acceptance levels were analyzed using the Rasch Modelling approach, a combination of the Wright map and logit value of item (LVI).

3. RESULTS AND DISCUSSION

This research examines the development of a remote-based physics experiment tool, PC R-PhyLab, designed to enhance the learning and teaching experience in the context of physics experiments. The system aims to provide an effective solution in carrying out Planck's constant experiments remotely to support equitable education. The development of PC R-PhyLab considers pedagogical principles and ease of access for users. This study evaluated the system architecture, tool functionality, validation by media experts, and user acceptance level.

3.1. PC R-PhyLab architecture

Figure 2 shows the system architecture of the remote experiment on the Planck constant device (PC R-PhyLab). As shown in Figure 2, the PC R-PhyLab architecture includes two main components: lab server and web server. The lab server uses the LabVIEW programming language to develop and run the graphical user interface (GUI) in the data acquisition software [28], allowing users to control laboratory devices during experiments remotely. On the other hand, the web server is equipped with Moodle learning management system (LMS) software, which provides learning materials and media, as well as communication features for interaction between users, teachers, and administrators [29], [30]. The system is designed to support an optimal learning experience by integrating relevant experimental materials and tools [31].

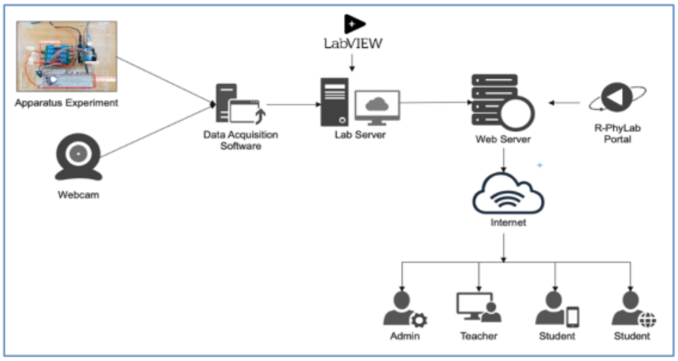

Figure 2. PC R-PhyLab architecture

3.2. PC R-PhyLab functionality test

The results of the PC R-PhyLab functionality test according to potential users are shown in Figure 3. The PC R-PhyLab functionality test results, as shown in Figure 3, showed good validity in various aspects. The environmental use aspect obtained the highest Aiken V index of 0.97, indicating that the PC R-PhyLab is suitable for remote experimentation. The pedagogical aspect also showed a high value of 0.95, signaling the effectiveness of PC R-PhyLab in supporting the learning process. In addition, the technical and UX aspects scored 0.93 each, indicating excellent technical quality and UX. The functionality aspect scores 0.91, indicating that the tool functions as expected. The economic and social aspects scored 0.88, above the validity cut-off value of 0.87, signaling that the tool fulfills the economic and social impact criteria. Although economic and social aspects are above the cut-off score, they are the lowest-scoring aspects compared to the other five aspects due to economic inequality and variations in geographical conditions in Indonesia [32]. These results indicate that the PC R-PhyLab has a high potential for use in educational contexts.

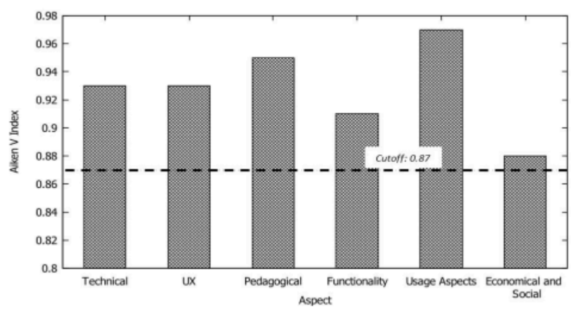

Figure 3. The functionality of PC R-PhyLab

The excellence in use environment aspect confirms that the PC R-PhyLab was designed with deep consideration of remote use conditions and needs, enabling optimal accessibility and functionality despite being in a different environment from a traditional laboratory. In the context of efforts to support educational equity, the ability of the PC R-PhyLab to function effectively in a remote setting is crucial [33]. By providing experimental solutions that can be accessed from various locations, the PC R-PhyLab supports the principle of educational inclusiveness by enabling users from different geographical and economic backgrounds to have equal opportunities in conducting physics experiments. This, in turn, contributes to educational equity by reducing access gaps and providing an equivalent quality of learning across regions.

The high pedagogical aspect rating also reflects that the PC R-PhyLab provides adequate technical features and is designed with profound pedagogical principles in mind. In remote experimentation, this effectiveness is crucial as it ensures that the quality of learning obtained by users remains equivalent to that obtained through traditional experiments in a physics laboratory. Using the PC R-PhyLab, students can conduct experiments remotely with a learning experience similar to hands-on experiments, thanks to an intuitive interface and relevant learning materials. In line with this, Atienza and Hussein [34] reported that using remote hardware in digital design courses resulted in equal or better learning outcomes for students. PC R-PhyLab ensures that users' interactions, manipulations, and observations in remote experiments still contain the same pedagogical qualities, thus supporting a deep and thorough understanding of physics concepts. Thus, PC R-PhyLab is essential in enhancing student understanding and providing a high-quality learning experience, even when conducted remotely.

3.3. Media expert validation results

Ten media experts assessed the quality of the PC R-PhyLab as a remote experimentation tool, and the results are shown in Figure 4. The validation by ten media experts, as shown in Figure 4, showed an excellent level of validity on the various aspects assessed. The user evaluation and feedback aspect obtained the highest Aiken V value of 0.95, signaling the tool's effectiveness in providing user feedback. The user interface and experiment functionality aspects scored 0.94, indicating that the interface and experiment functionality of the PC R-PhyLab are adequate. The user support aspect also scored highly at 0.93, indicating that the tool provides excellent user support. The multimedia quality aspect scored 0.90, indicating that the multimedia component of the tool is of high quality. The accessibility aspect scored 0.87, indicating that the tool is quite accessible. Finally, the technology and performance and integration and collaboration aspects scored 0.88, indicating solid technological performance and adequate integration capabilities. All aspects tested showed validity above the validity cut-off value of 0.73, signaling that PC R-PhyLab is a quality experimental tool and is ready to use.

The user evaluation and feedback aspect received the highest rating, signifying the outstanding effectiveness of PC R-PhyLab in providing constructive and timely feedback to users. The high score on the user evaluation and feedback aspect indicates that the system can collect and analyze data accurately and provide useful and relevant feedback that users can directly apply. This effective feedback system is a key component in the learning process [35], as it allows users to understand their experimental results in depth and immediately recognize areas that require further improvement. With integrated and responsive feedback, users can make the necessary adjustments in their approach to experiments, improving the overall effectiveness of their learning. In addition, this powerful feedback system supports adaptive learning, where users can learn from their mistakes and refine their understanding in real-time. This contributes to the reinforcement of acquired knowledge and skills, making PC R-PhyLab an efficient tool not only in the execution of experiments but also in the process of evaluation and continuous learning.

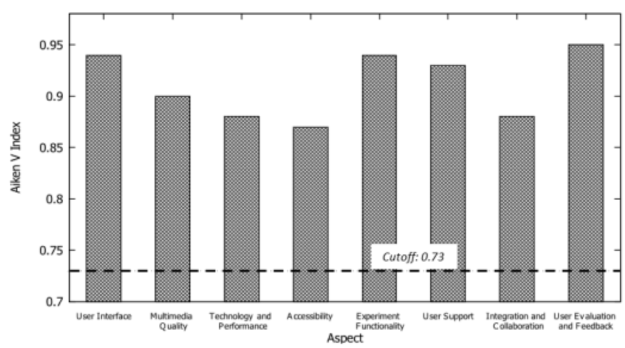

Figure 4. Media expert validation results on PC R-PhyLab

3.4. User acceptance of PC R-PhyLab

Figure 5, Wright map, shows the level of acceptance of the PC R-PhyLab among users. Based on the user acceptance test results shown in Figure 5, PC R-PhyLab obtained excellent results with a higher average logit person than logit item. Of the four aspects evaluated, 80% (24 out of 30) items were in the medium and high acceptance level categories. The ease to use aspect had the highest logit value of 0.52, falling into the high acceptance level category, indicating that users found the tool very easy to use. This is followed by the ease of learning aspect with a logit value of 0.30, also in the high acceptance level category, indicating that this tool is relatively easy to learn.

Meanwhile, the satisfaction and usefulness aspects have logit values of -0.40 and -0.51, respectively, which fall into the medium acceptance level category. These values indicate that there is room for improvement in terms of satisfaction and usability of the tool, although the judgments are not overly negative. Overall, while ease of use and learning received positive ratings, there is a need to improve the satisfaction and usability aspects to achieve a higher level of acceptance.

A high score on the ease to use aspect indicates that the PC R-PhyLab was designed with an intuitive and user-friendly interface, which significantly eases the user's interaction with the system. The availability of clear and detailed user instructions also contributes to this ease of use. The comprehensive documentation, including step-by-step guides, tutorials, and FAQs, ensures that users can quickly understand how to operate the apparatus without difficulty. These instructions for use not only help reduce the learning curve but also increase efficiency in using the tool, allowing users to focus on experiments and data analysis rather than learning how to use the system [24], [36]. Thus, the ease of use of the PC R-PhyLab is due not only to the ergonomic interface design but also to the comprehensive documentation support, which together enhances the overall UX.

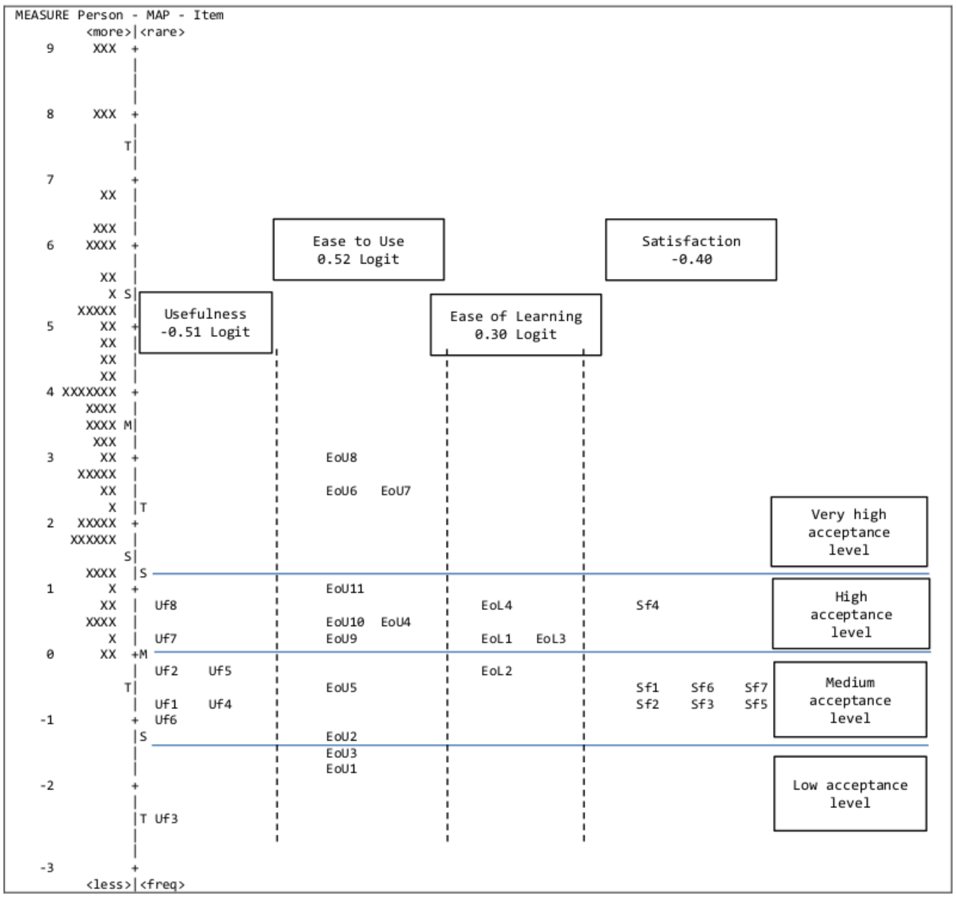

Figure 5. User acceptance level of PC R-PhyLab

4. CONCLUSION

The study concluded that the R-PhyLab PC is a high-quality remote physics experiment tool with strong validity in various aspects. The system architecture supports an optimal learning experience, and the results of functionality testing and validation by media experts show that the R-PhyLab PC meets the criteria of quality, user support, and social impact. Although the user acceptance rate shows promising results in terms of ease of use and learning, there is a need for improvement in the satisfaction and usability aspects of the tool.

This study has some limitations, especially in the satisfaction and usability aspects, which require improvement despite the positive assessment of ease of use and learning. In addition, this study has yet to fully explore how the R-PhyLab PC can be applied in diverse educational contexts across Indonesia, especially in areas with limited infrastructure. For future research, it is recommended that in-depth studies be conducted that evaluate user satisfaction, identify factors that influence tool usability, and test the implementation of PC R-PhyLab across different infrastructure conditions and economic backgrounds to ensure this solution is widely accessible and effective across Indonesia.

The implications of this research include several things. First, the development of a remote physics laboratory (R-PhyLab) can reduce the gap in education access in areas with limited laboratory facilities, especially in remote areas or with low economic conditions. Secondly, this solution allows students in different regions to still get quality practicum experiences without having to be physically present, thus supporting more inclusive and equitable learning. Third, this research also encourages the adoption of technology in science learning, opening up opportunities for further innovation in the education sector.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Toni Kus Indratno	✓		✓			✓	✓		✓	✓			✓	
Ariati Dina Puspitasari		✓		✓		✓		✓		✓	✓			
Yoga Dwi Prabowo			✓	✓		✓	✓			✓	✓		✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author [I], upon reasonable request.

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