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Penulis : **Ishafit**, Moh. Irma Sukarelawan, Toni Kus Indratno, Ariati Dina Puspitasari, Yoga Dwi Prabowo

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#32384 Summary

SUMMARY REVIEW EDITING

Submission

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Title and Abstract

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

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.

Indexing

Keywords: Education inequality; PC R-PhyLab; Planck's constant; Remote experiment; Remote physics laboratory

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Dear Prof/Dr/Mr/Mrs. Ishafit Ishafit,

We have reached a decision regarding your submission entitled "Development of a Remote Physics Laboratory to Support Equitable Access to Education" to International Journal of Evaluation and Research in Education (IJERE), p-ISSN: 2252-8822, e-ISSN: 2620-5440, a Scopus (https://www.scopus.com/sourceid/21100934092) and Scimagojr (https://www.scimagojr.com/journalsearch.php?q=21100934092&tip=sid&clean=0) indexed journal.

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Please submit your revised paper in MS Word file format, and submit revised paper within 8 weeks through our online system at same ID number (NOT as new submission) on Tab "Review" as "Author Version" file. Then, your revised paper will be judged for final decision of acceptance or rejection.

I look forward for hearing from you

Thank you

Best Regards,
Assoc. Prof. Dr. Lina Handayani
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Reviewer A:

Please answer the following questions!
- Why did you do the study?
- Why is the study relevant?
- What did you do?
- What approach did you use?
- What did you find?
- What did you conclude?

Reorganize your abstract by stating the problem clearly, proposing a solution or approach, and emphasizing key findings and conclusion within 150-200 words.

Writing a discussion can be a delicate balance between summarizing your results, providing proper context for your research and avoiding introducing new information. Remember that your paper should be both confident and honest about the results!

What are the implications of your findings? What will be helpful in the future?

Reviewer B:

Please provide responses and explanations for the following questions.
1. What is the scientific question you are addressing?
2. What is the key finding that answers this question?
3. What is the nature of the evidence you provide in support of your conclusion?
4. What significance do your results have for the field and the broader community?
5. Is there additional information that we should take into account?

This paper contains no critical discussion or interpretation.
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-

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The IJERE form to evaluate submitted papers
Content:
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Comments to the Author

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**The manuscript “Development of a Remote Physics Laboratory to Support Equitable Access to Education” still needs improvement.
Please follow the suggested improvements below:

- Check each paragraph in the body of the text and make sure no paragraph is less than 3 sentences, if less, combine it with the paragraph after/previous to it or add more sentences.
(Check chapter 3.3 Media Expert Validation Results, 3.2 PC R-PhyLab Functionality Test)
- Remove/replace local references by citing from reputable international journals.

(Reference numbers [7], and [8])
- The INTRODUCTION section must also include the research questions/hypotheses.

**It is important that you follow the writing on the template in as much detail as possible http://iaescore.com/gfa/ijere.docx

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Matrices of Amendments for Round 1

Comments and Suggestions for Authors	**Author's Responds**
Reviewer A Please answer the following questions! - Why did you do the study? - Why is the study relevant? - What did you do? - What approach did you use? - What did you find? - What did you conclude?	Why did you do the study? This research was conducted to minimize the gap in educational opportunities, especially in physics education, which requires laboratory access in Indonesia due to geographical conditions and differences in economic levels. Why is the study relevant? This research is relevant because many campuses in Indonesia, especially in remote and less developed areas, do not have access to adequate physics laboratories due to difficult geographical conditions and differences in economic levels. By developing remote physics laboratories, students in these areas can still conduct experiments and learn practically without having expensive physical facilities. This helps to narrow the gap in access to physics education, allowing all students, regardless of location or economic conditions, to have an equal learning experience. What did you do? To provide equal access to physics laboratories, we developed a physics lab tool that can be accessed remotely. What approach did you use? The approach we use is through development research to produce a product in the form of R-PhyLab that can be utilized by those who need it. What did you find? The main finding of this research is that remote physics laboratories can support physics learning, especially on campuses that do not have access to physical laboratories. The use of this technology allows students to conduct physics experiments remotely, which still provides a similar practical experience to a live physical laboratory. In addition, this study shows that this remote laboratory model is able to overcome geographical barriers and economic disparities, thus helping to expand access to physics education more evenly across Indonesia. What did you conclude? The results show that PC R-PhyLab is a quality remote-based physics experiment tool with high validity in various aspects. The system architecture supports an optimal learning experience, and the results of the functionality test and media expert validation show that it meets the criteria in terms of quality, user support, and social impact.
Reorganize your abstract by stating the problem clearly, proposing a solution or approach, and emphasizing key findings	We have rearranged the abstracts.

Comments and Suggestions for Authors	Author's Responds
and conclusion within 150-200 words.	
Writing a discussion can be a delicate balance between summarizing your results, providing proper context for your research and avoiding introducing new information. Remember that your paper should be both confident and honest about the results! What are the implications of your findings? What will be helpful in the future?	We have added research implications to the last paragraph of the conclusion section.
Reviewer B Please provide responses and explanations for the following questions. 1. What is the scientific question you are addressing? 2. What is the key finding that answers this question? 3. What is the nature of the evidence you provide in support of your conclusion? 4. What significance do your results have for the field and the broader community? 5. Is there additional information that we should take into account?	1. What is the scientific question you are addressing? a. Can the developed R-PhyLab function as planned? b. Does R-PhyLab have good quality? c. Is R-PhyLab acceptable to potential users? d. Does R-PhyLab potentially minimize the gap in access to physics laboratories due to georgraphic problems and economic inequality? 2. What is the key finding that answers this question? The main finding is that a remote physics experiment tool has been developed that has been tested for quality and is well received by potential users. 3. What is the nature of the evidence you provide in support of your conclusion? To support our conclusion: a. The developed R-PhyLab remote experimentation tool has the level of functionality as designed, b. R-PhyLab has been tested to quality standards by experts, and c. R-PhyLab can be accepted by prospective users. 4. What significance do your results have for the field and the broader community? This research has an important meaning in providing equal access to education, especially physics experiments, for students so that it has an impact on mastery of physics content. 5. Is there additional information that we should take into account? The research has the potential for further development given that there are still limited studies that report on the issue we raised. This issue also has tremendous potential to be studied from various perspectives. For example, how is the impact of its implementation

Comments and Suggestions for Authors	Author's Responds
	(learning effectiveness), how is the digital divide or digital divide problem in geographically isolated areas. It can even be expanded related to policy support from the government or educational institutions to ensure the implementation of distance laboratories in a sustainable manner?
Reviewer C **The manuscript "Development of a Remote Physics Laboratory to Support Equitable Access to Education" still needs improvement. Please follow the suggested improvements below: - Check each paragraph in the body of the text and make sure no paragraph is less than 3 sentences, if less, combine it with the paragraph after/previous to it or add more sentences. (Check chapter 3.3 Media Expert Validation Results, 3.2 PC R-PhyLab Functionality Test) - Remove/replace local references by citing from reputable international journals. (Reference numbers [7], and [8]) - The INTRODUCTION section must also include the research questions/hypotheses.	We have ensured that there are no more paragraphs of less than 3 sentences in sections 3.2 and 3.3. References [7] and [8] have been removed. Research questions have been added at the end of the introduction.
Reviewer D Economic and social being the lowest Aiken V index despite above the validity cut off value. Please explain the reason as it being the lowest? Is it related to the ecomic inequality and variations in geographical conditions perhaps?	Economic and social being the lowest Aiken V index despite being above the validity cut-off value. Please explain the reason as it being the lowest? Is it related to economic inequality and variations in geographical conditions, perhaps? Although the economic and social aspects are above the cut-off value, they are the lowest scoring aspects compared to the other five aspects due to economic inequality and variations in geographical conditions in Indonesia. (We have included in sub **3.2 PC R-PhyLab Functionality Test** first paragraph)

Revised version #1 submitted

22 Oktober 2024

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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 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 unfavourable 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], [15], virtual laboratories [16]–[18] to remote laboratories [19]–[23]. 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 [24], [25].

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 [26], [27]. 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 [28]. 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. For example, on the topic of polarization [22], the topic of magnetic fields [21], and the topic of fluids [20]. 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.

Research Questions: (1) Does the developed R-PhyLab have good functionality?; (2) Does R-PhyLab have good quality according to media experts?; (3) 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 & 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.

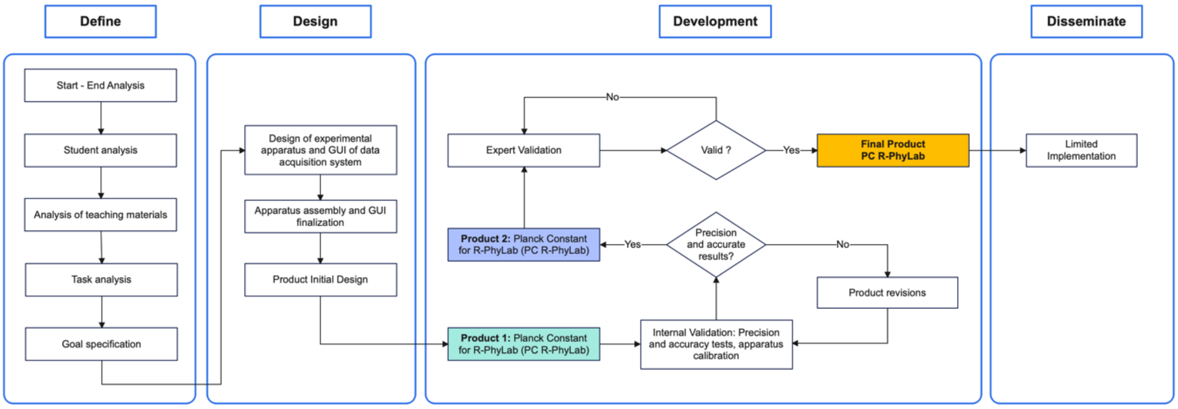

Figure 1. Flowchart of product development procedure design

2.2 Research Respondents

Based on the development procedures that have been carried out, five students were involved in the PC R-PhyLab functionality test stage. Ten physics education lecturers acted as media experts to assess the feasibility of the apparatus from the media aspect. To obtain data stability with 0.5 logit accuracy and 95% confidence level, a sample size of 64-144 is recommended [29]. Therefore, 84 physics education students involved in the user acceptance test met the requirements.

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. USE Questionnaire (Usefulness, Satisfaction, and Ease of Use) 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 [30].

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) [31], [32].

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 [33], 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 [34], [35]. The system is designed to support an optimal learning experience by integrating relevant experimental materials and tools.

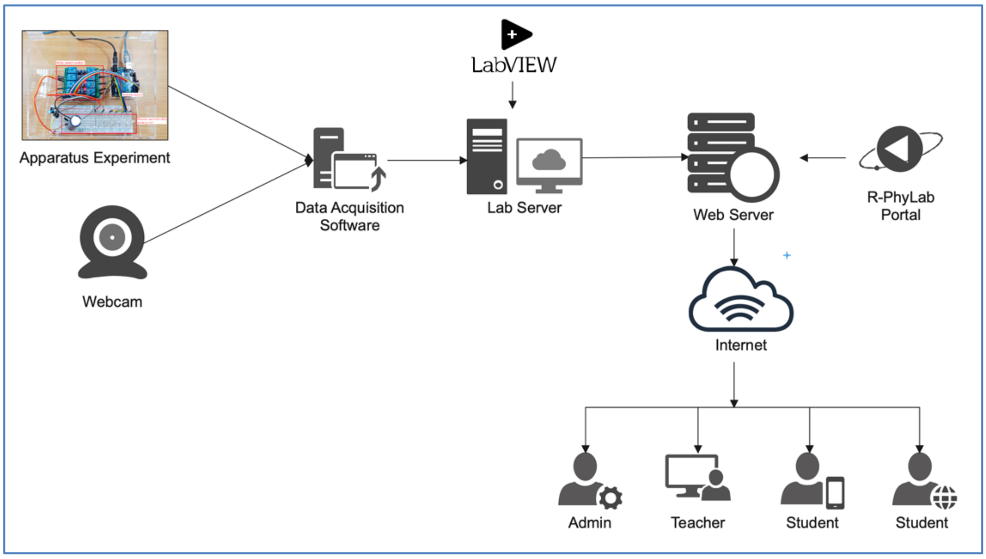

Figure 2. PC R-PhyLab Architecture

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 User Experience aspects scored 0.93 each, indicating excellent technical quality and user experience. 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. These results indicate that the PC R-PhyLab has a high potential for use in educational contexts.

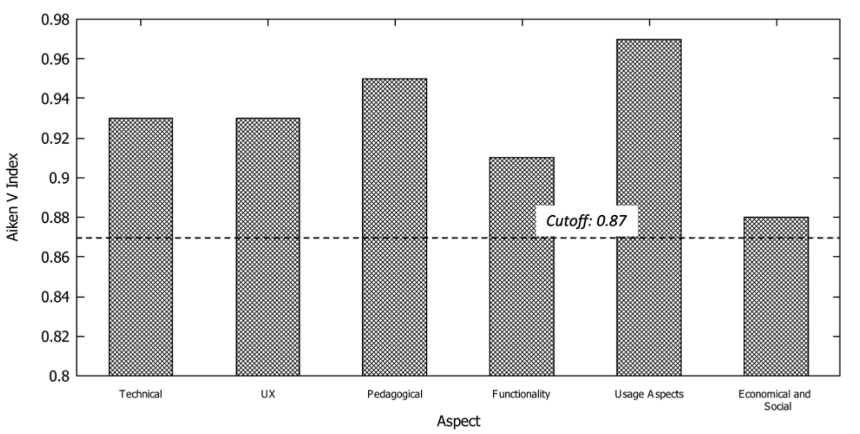

Figure 3. The functionality of PC R-PhyLab

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 [36]. 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, [37] 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 5. 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.

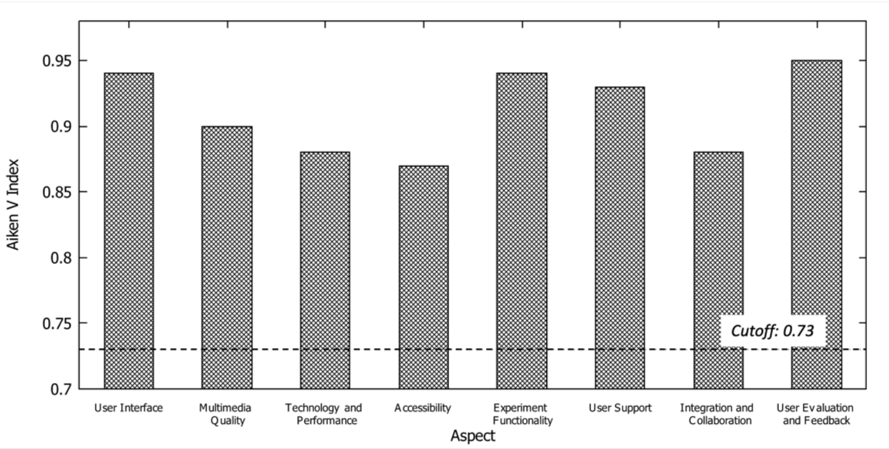

Figure 4. Media expert validation results on PC R-PhyLab

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 [38], 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.

3.4 User Acceptance of PC R-PhyLab

Figure 5 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.

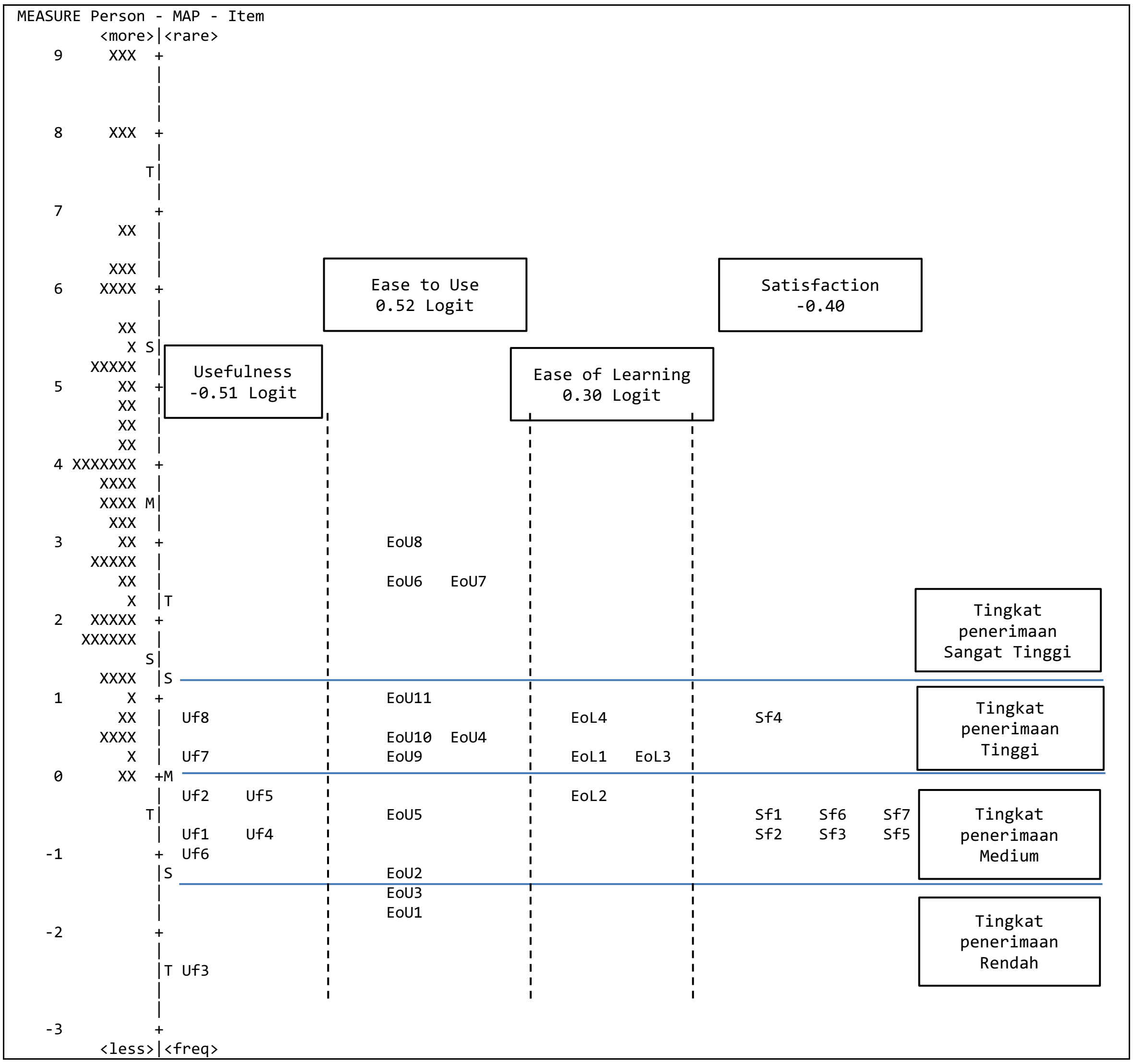

Figure 5. User Acceptance Level of PC R-PhyLab

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 tool 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 [39]. 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 user experience.

4. CONCLUSION

The conclusion of this study shows 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.

ACKNOWLEDGEMENTS

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Revisions required #2

31 Oktober 2024

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Toni Kus Indratno <tonikus@staff.uad.ac.id>

[IJERE] Editor Decision

1 pesan

Dr. Lina Handayani <ijere@iaescore.com> 31 Oktober 2024 pukul 19.16
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Dear Prof/Dr/Mr/Mrs: Ishafit Ishafit,

We have reached a decision regarding your submission entitled "Development of a Remote Physics Laboratory to Support Equitable Access to Education" to International Journal of Evaluation and Research in Education (IJERE), a SCOPUS (https://www.scopus.com/sourceid/21100934092) and ERIC indexed journal (https://bit.ly/2EI8hDj).

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Please prepare your revised paper (in MS Word or LATEX file format) adheres every detail of the guide of authors (https://iaescore.com/gfa/ijere.docx for MS Word file format, or https://iaescore.com/gfa/ijere.rar for LATEX file format), and check it for spelling/grammatical mistakes.

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=========
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For ORIGINAL/RESEARCH PAPER: the paper should be presented with IMRaD model:
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We will usually expect a minimum of 30 references primarily to journal papers. Citations of textbooks should be used very rarely and citations to web pages should be avoided. All cited papers must be referenced within the body text of the manuscript.

For REVIEW PAPER: the paper should present a critical and constructive analysis of existing published literature in a field, through summary, classification, analysis and comparison. The function and goal of the review paper is:
1) to organize literature;
2) to evaluate literature;
3) to identify patterns and trends in the literature;
4) to synthesize literature; or
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The structure of a review paper includes:
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2. Abstract – includes a description of subjects covered.
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Number of minimum references for review paper is 50 references (included minimum 40 recently journal articles).

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Reviewer A:

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Content:
Good

Significance:
Fair

Originality:
Good

Relevance:
Good

Presentation:
Good

Recommendation:
Good

Comments to the Author

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:
**The manuscript "Development of a Remote Physics Laboratory to Support Equitable Access to Education" still needs improvement.
I hope you can follow the suggestions for improvement below in detail:

- The DISCUSSION section should be supported by at least 10 references for comparison of previous studies.
- Check each word on each figure and increase the size/resolution of the figure so that each word can be read clearly by the reader and make sure the size of the figure matches the size of the paper page.
(Every word in the figure 1 is not clear)
- Check every word in the each figures and change every word that uses local language into English.
(Figure 5)

Reviewer B:

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Content:
Significance:
Originality:
Relevance:
Presentation:
Recommendation:

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Reviewer C:

The IJERE form to evaluate submitted papers
Content:
Good

Significance:
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Originality:
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Recommendation:
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:
Explain on how respondents were selected – students and teachers (e.g: criteria and sampling technique)
Please provide the reliability and validity of the adapted instruments

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Reviewer D:

The IJERE form to evaluate submitted papers
Content:
Good

Significance:
Good

Originality:
Very good

Relevance:
Good

Presentation:
Good

Recommendation:
Good

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Reviewer C Explain on how respondents were selected – students and teachers (e.g: criteria and sampling technique) Please provide the reliability and validity of the adapted instruments	We have revised section 2.2 Research Respondents
Reviewer D fix the figures	We have adjusted the text/resolution in each Figure

Revised version #2 submitted

13 November 2024

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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 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 unfavourable 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], [15], virtual laboratories [16]–[18] to remote laboratories [19]–[23]. 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 [24], [25].

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 [26], [27]. 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 [28]. 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. For example, on the topic of polarization [22], the topic of magnetic fields [21], and the topic of fluids [20]. 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.

Research Questions: (1) Does the developed R-PhyLab have good functionality?; (2) Does R-PhyLab have good quality according to media experts?; (3) 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 & 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.

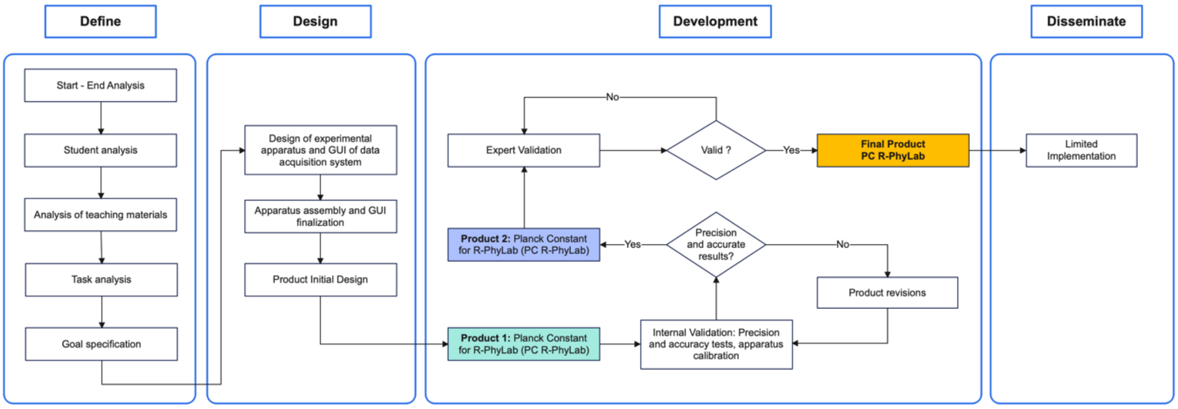

Figure 1. Flowchart of product development procedure design

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 [29]. Ten 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: (1) physics education lecturers who focus on experimental physics, (2) have a minimum degree of master of physics education, (3) have a minimum teaching experience of 3 years, and (4) have the ability to evaluate learning instruments. The exclusion criteria are: (1) Have no experience in developing physics experimental tools, (2) Not competent in the field of educational technology, and (3) 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 [30]. 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.

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. USE Questionnaire (Usefulness, Satisfaction, and Ease of Use) 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 [31].

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) [32], [33].

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 [34], 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 [35], [36]. The system is designed to support an optimal learning experience by integrating relevant experimental materials and tools [37].

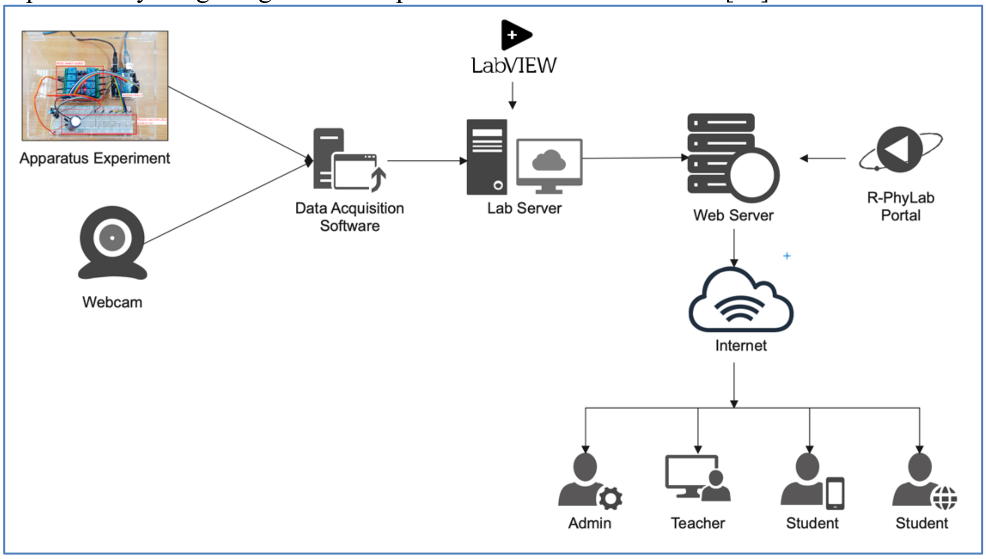

Figure 2. PC R-PhyLab Architecture

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 User Experience aspects scored 0.93 each, indicating excellent technical quality and user experience. 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 [38]. These results indicate that the PC R-PhyLab has a high potential for use in educational contexts.

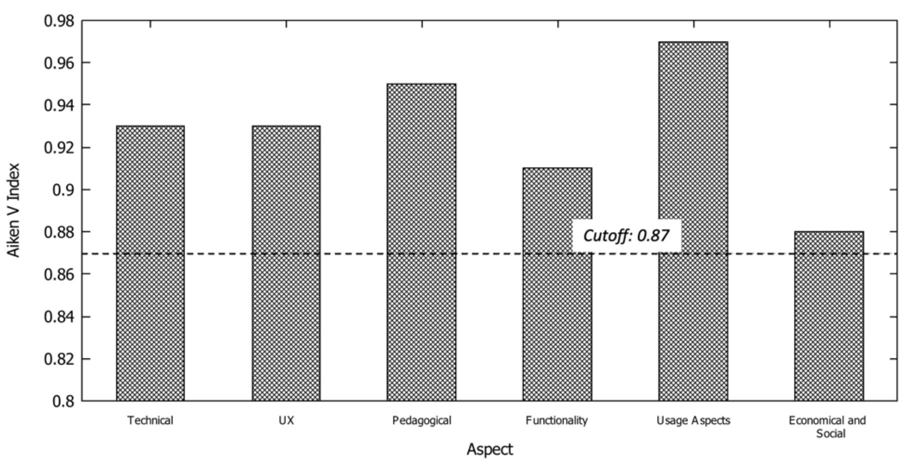

Figure 3. The functionality of PC R-PhyLab

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 [39]. 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, [40] 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.

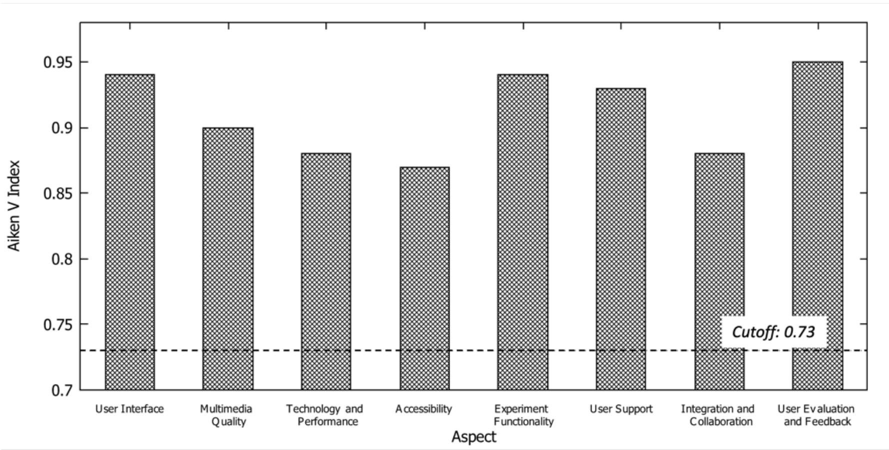

Figure 4. Media expert validation results on PC R-PhyLab

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 [41], 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.

3.4 User Acceptance of PC R-PhyLab

Figure 5, Wright map [42], 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 [43], [44]. 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 user experience.

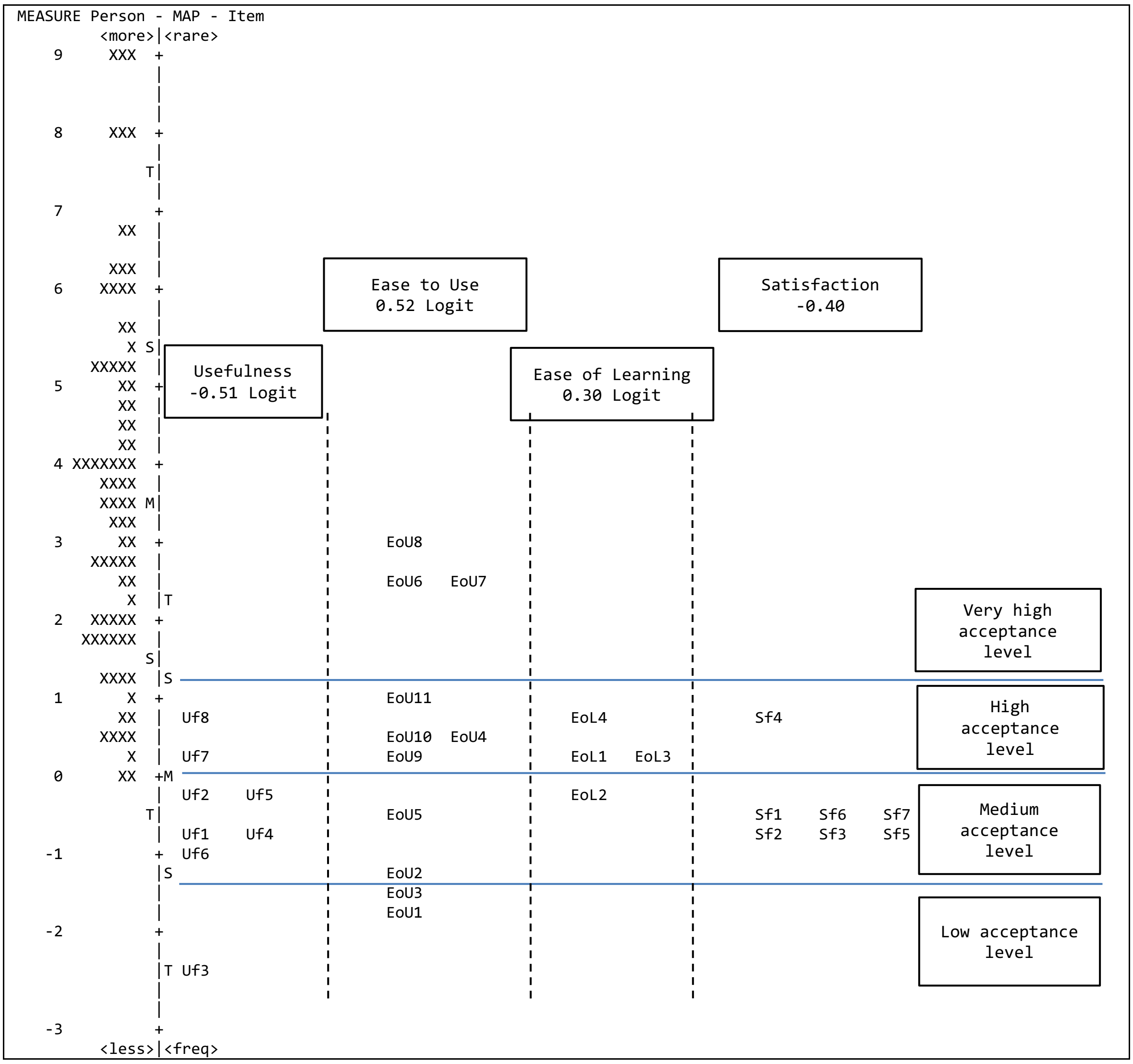

Figure 5. User Acceptance Level of PC R-PhyLab

4. CONCLUSION

The conclusion of this study shows 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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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 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 unfavourable 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], [15], virtual laboratories [16]–[18] to remote laboratories [19]–[23]. 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 [24], [25].

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 [26], [27]. 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 [28]. 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. For example, on the topic of polarization [22], the topic of magnetic fields [21], and the topic of fluids [20]. 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.

Research Questions: (1) Does the developed R-PhyLab have good functionality?; (2) Does R-PhyLab have good quality according to media experts?; (3) 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 & 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.

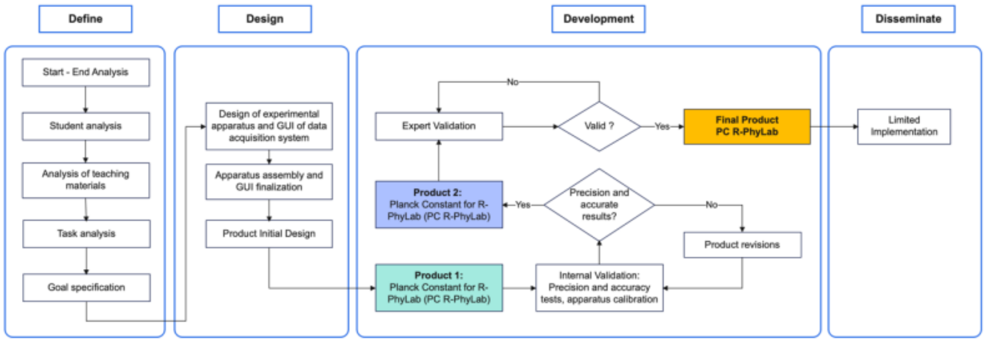

Figure 1. Flowchart of product development procedure design

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 [29]. Ten 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: (1) physics education lecturers who focus on experimental physics, (2) have a minimum degree of master of physics education, (3) have a minimum teaching experience of 3 years, and (4) have the ability to evaluate learning instruments. The exclusion criteria are: (1) Have no experience in developing physics experimental tools, (2) Not competent in the field of educational technology, and (3) 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 [30]. 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.

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. USE Questionnaire (Usefulness, Satisfaction, and Ease of Use) 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 [31].

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) [32], [33].

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 [34], 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 [35], [36]. The system is designed to support an optimal learning experience by integrating relevant experimental materials and tools [37].

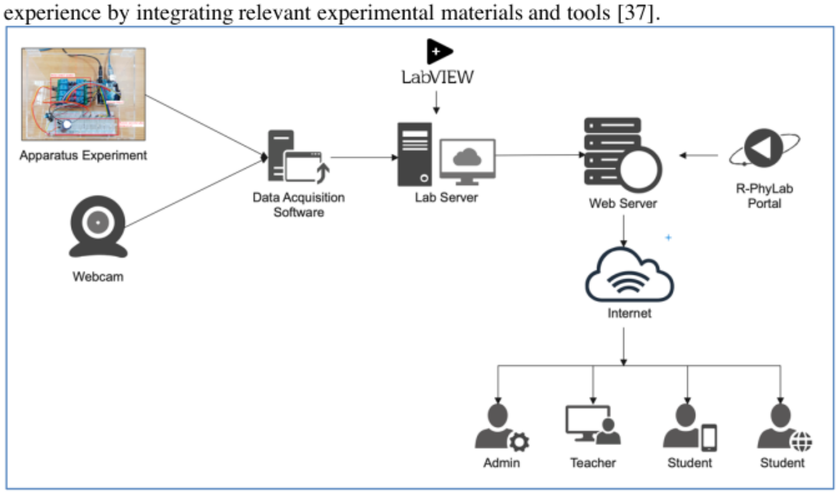

Figure 2. PC R-PhyLab Architecture

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 User Experience aspects scored 0.93 each, indicating excellent technical quality and user experience. 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 [38]. These results indicate that the PC R-PhyLab has a high potential for use in educational contexts.

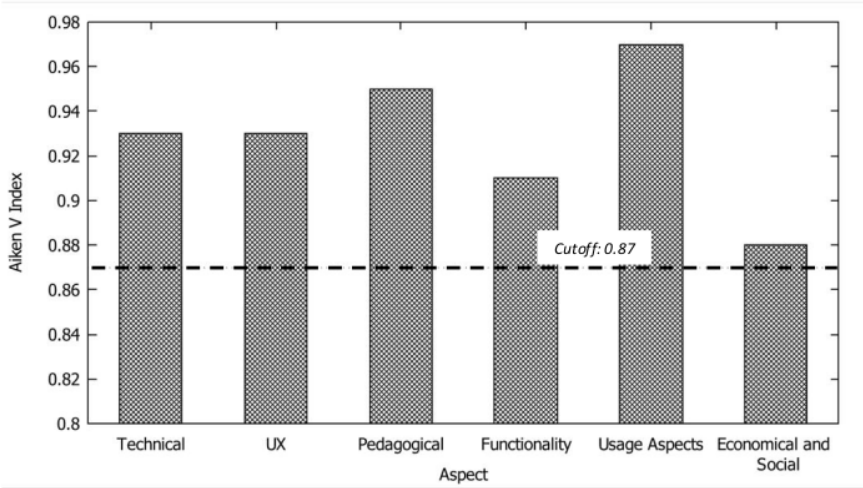

Figure 3. The functionality of PC R-PhyLab

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 [39]. 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, [40] 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.

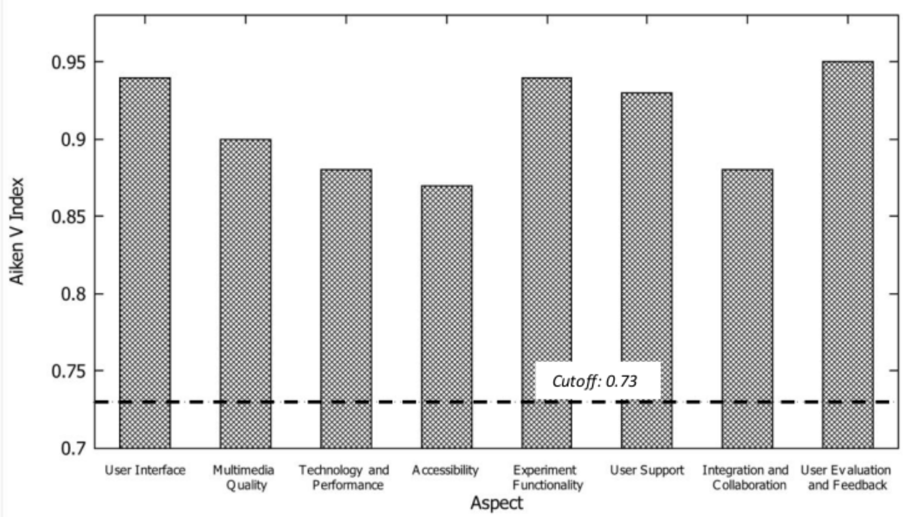

Figure 4. Media expert validation results on PC R-PhyLab

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 [41], 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.

3.4 User Acceptance of PC R-PhyLab

Figure 5, Wright map [42], 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.

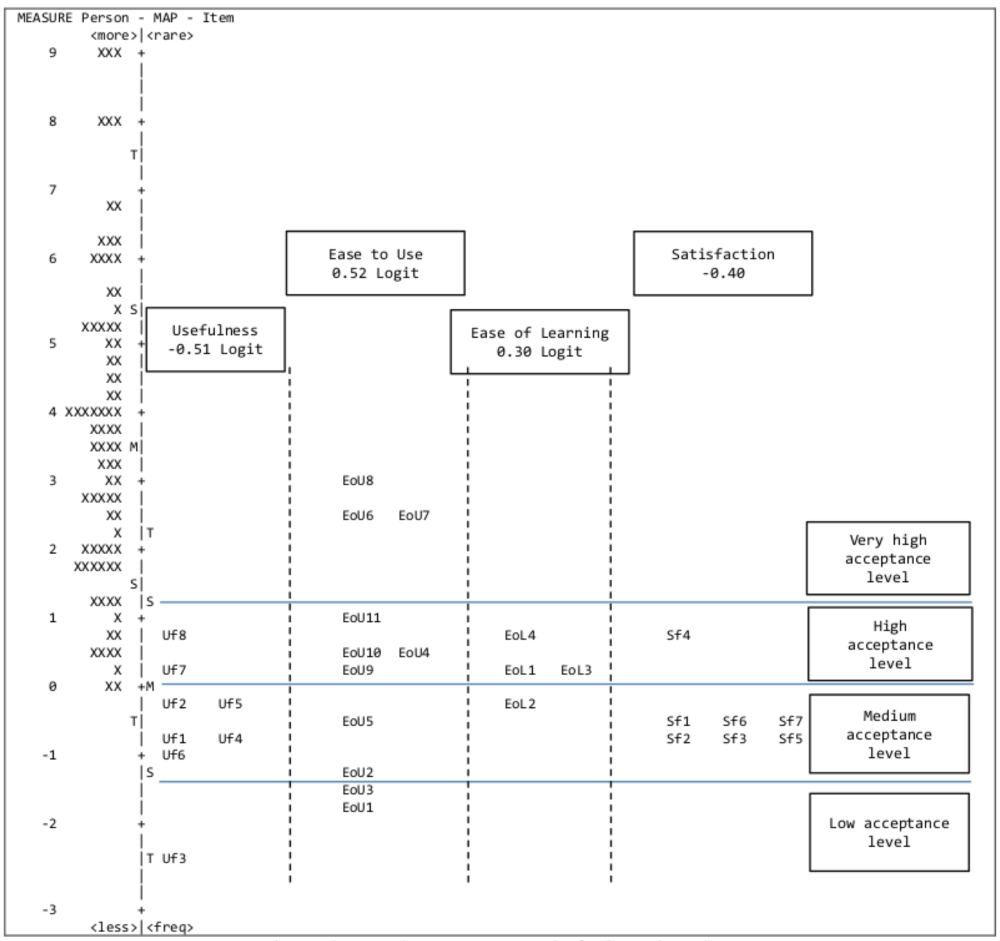

Figure 5. User Acceptance Level of PC R-PhyLab

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 [43], [44]. 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 user experience.

4. CONCLUSION

The conclusion of this study shows 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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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 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 unfavourable 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], [15], virtual laboratories [16]–[18] to remote laboratories [19]–[23]. 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 [24], [25].

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 [26], [27]. 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 [28]. 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. For example, on the topic of polarization [22], the topic of magnetic fields [21], and the topic of fluids [20]. 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.

Research Questions: (1) Does the developed R-PhyLab have good functionality?; (2) Does R-PhyLab have good quality according to media experts?; (3) 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 & 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.

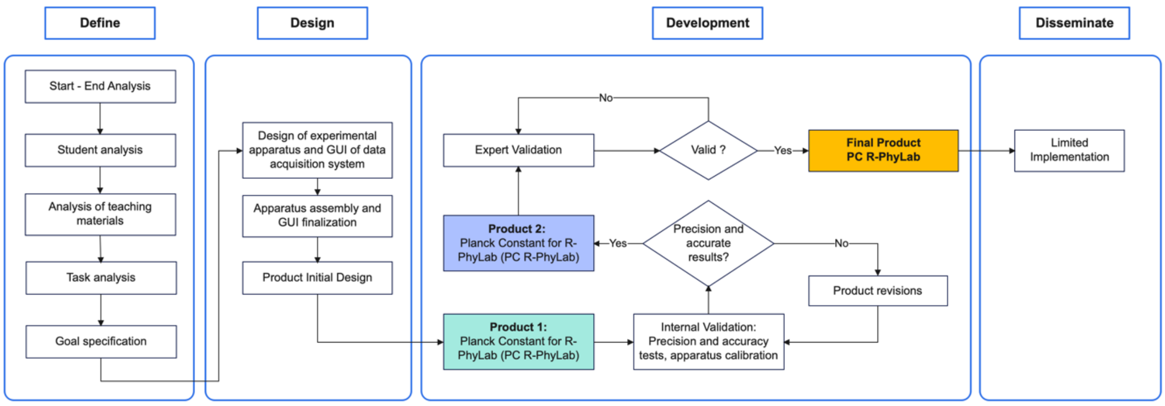

Figure 1. Flowchart of product development procedure design

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 [29]. Ten 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: (1) physics education lecturers who focus on experimental physics, (2) have a minimum degree of master of physics education, (3) have a minimum teaching experience of 3 years, and (4) have the ability to evaluate learning instruments. The exclusion criteria are: (1) Have no experience in developing physics experimental tools, (2) Not competent in the field of educational technology, and (3) 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 [30]. 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.

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. USE Questionnaire (Usefulness, Satisfaction, and Ease of Use) 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 [31].

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) [32], [33].

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 [34], 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 [35], [36]. The system is designed to support an optimal learning experience by integrating relevant experimental materials and tools [37].

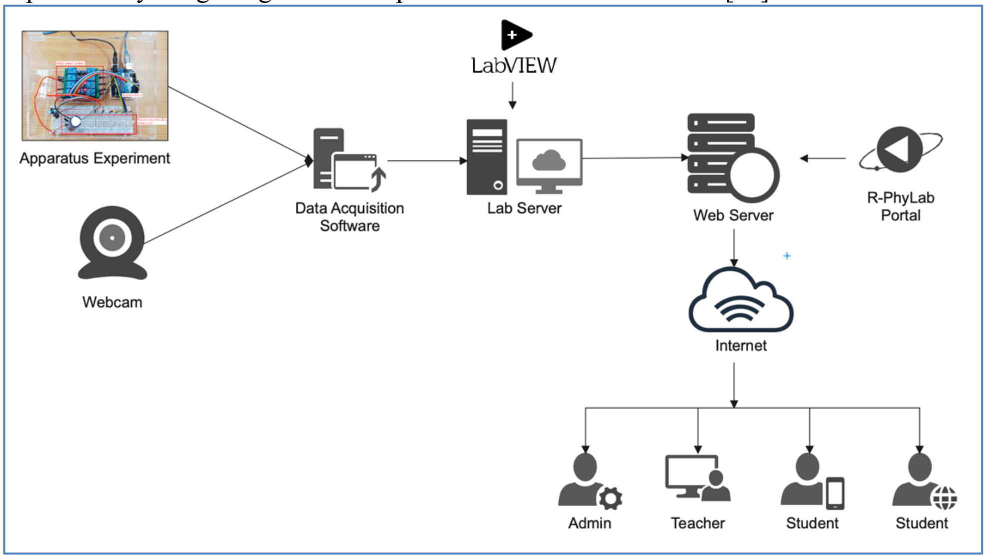

Figure 2. PC R-PhyLab Architecture

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 User Experience aspects scored 0.93 each, indicating excellent technical quality and user experience. 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 [38]. These results indicate that the PC R-PhyLab has a high potential for use in educational contexts.

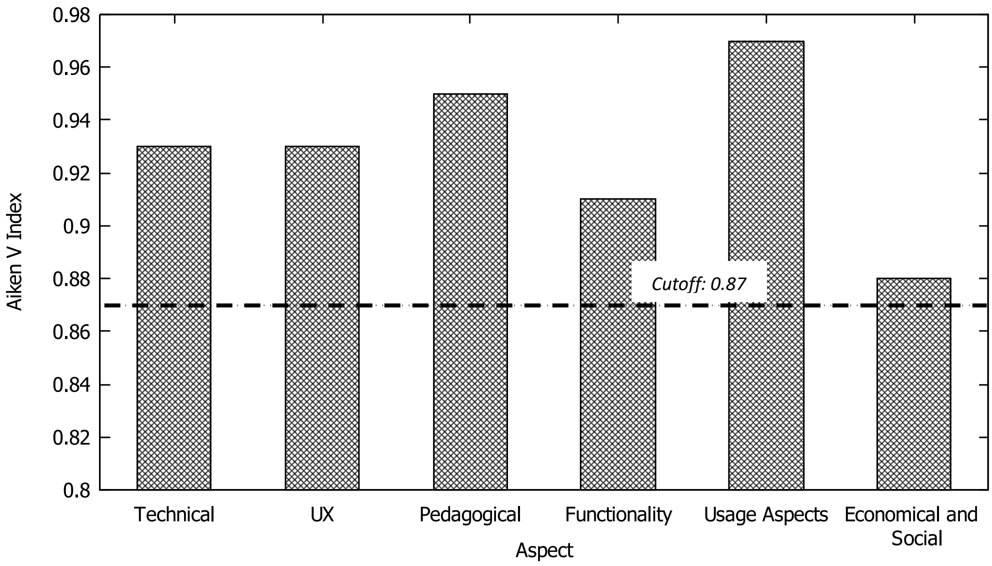

Figure 3. The functionality of PC R-PhyLab

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 [39]. 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, [40] 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.

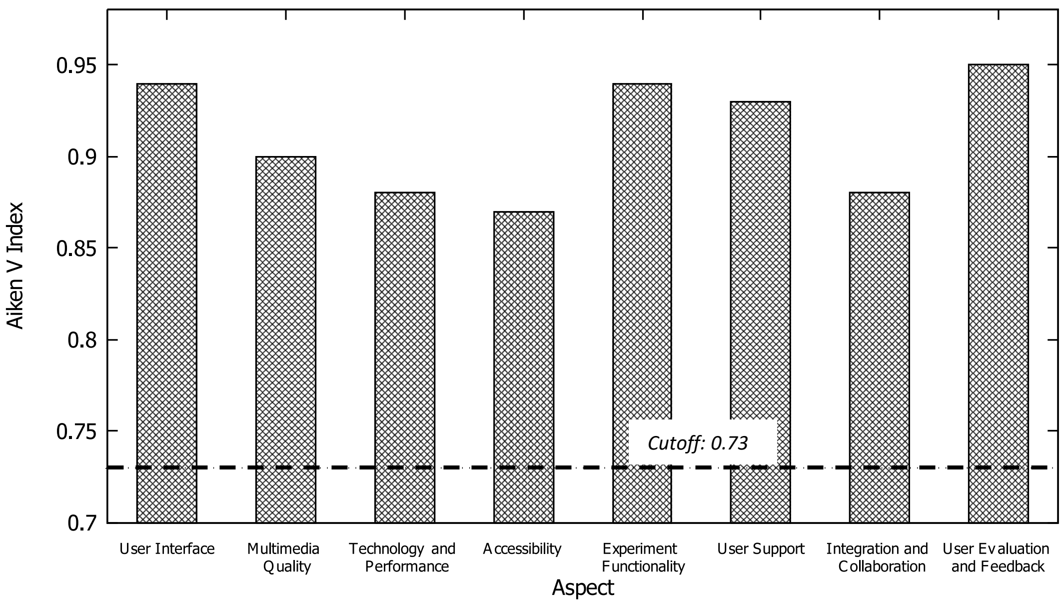

Figure 4. Media expert validation results on PC R-PhyLab

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 [41], 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.

3.4 User Acceptance of PC R-PhyLab

Figure 5, Wright map [42], 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.

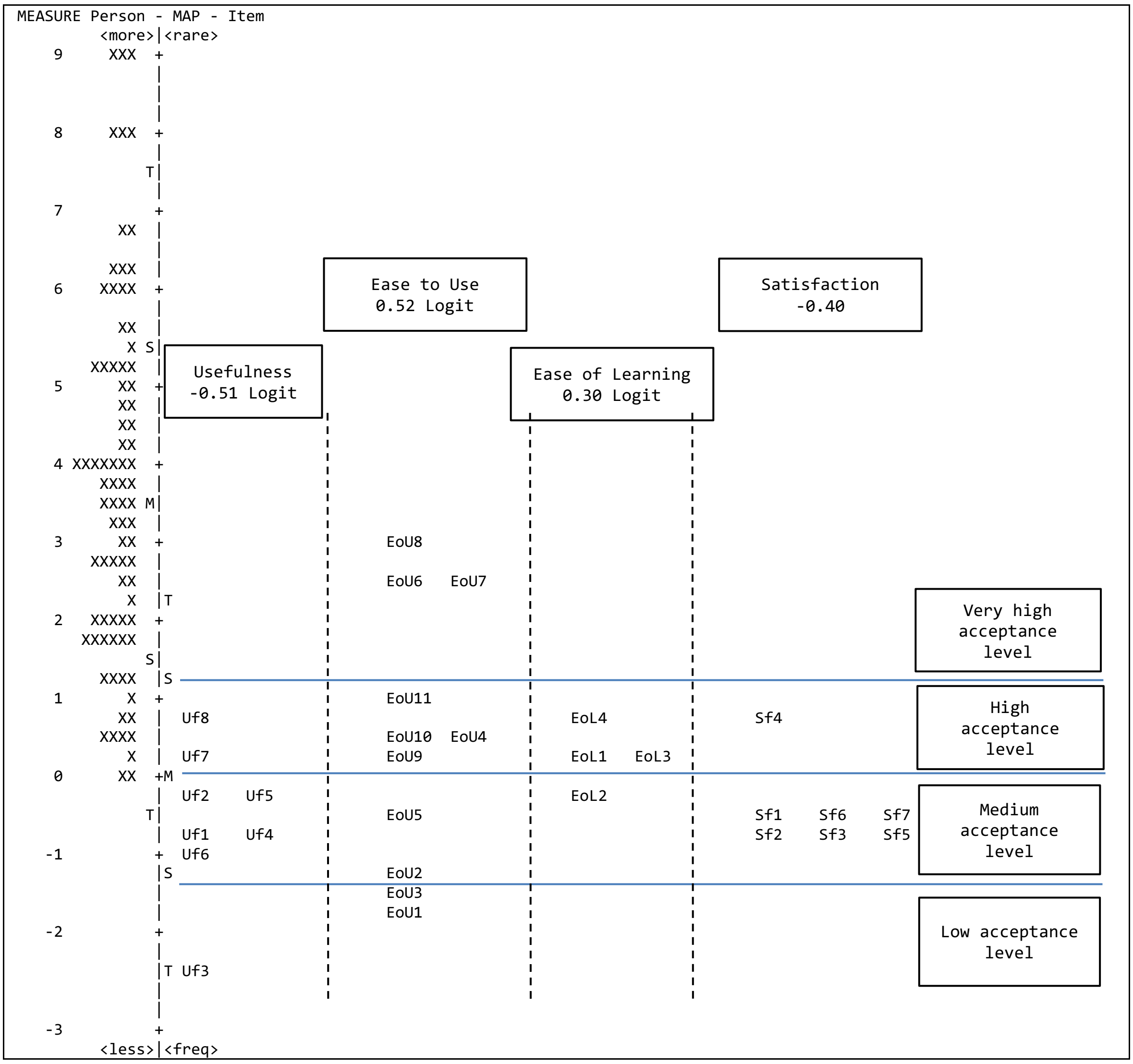

Figure 5. User Acceptance Level of PC R-PhyLab

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 [43], [44]. 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 user experience.

4. CONCLUSION

The conclusion of this study shows 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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Best regards
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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.

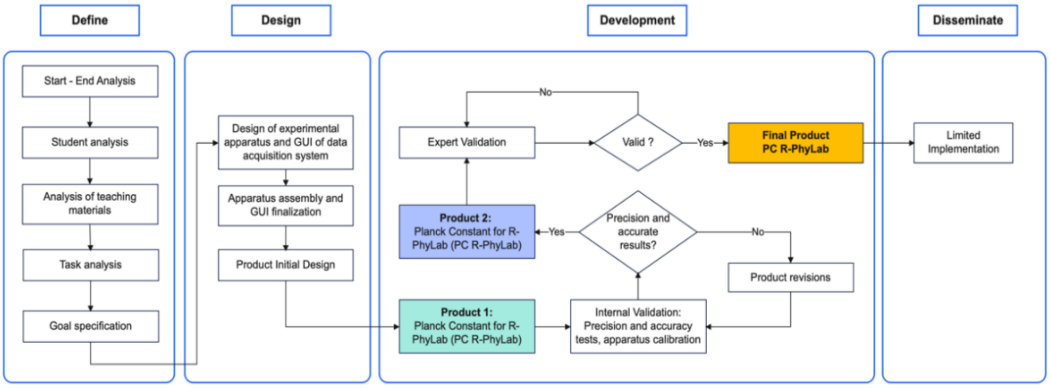

Figure 1. Flowchart of product development procedure design

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].

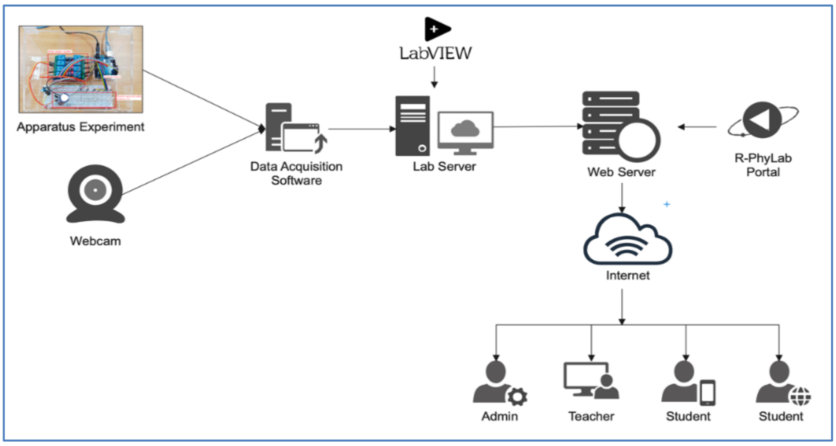

Figure 2. PC R-PhyLab architecture

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.

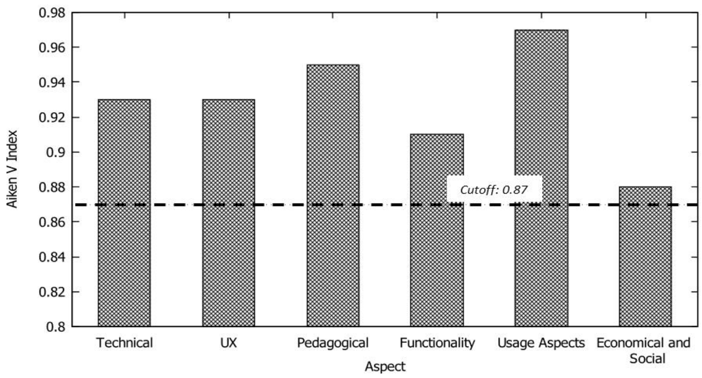

Figure 3. The functionality of PC R-PhyLab

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.

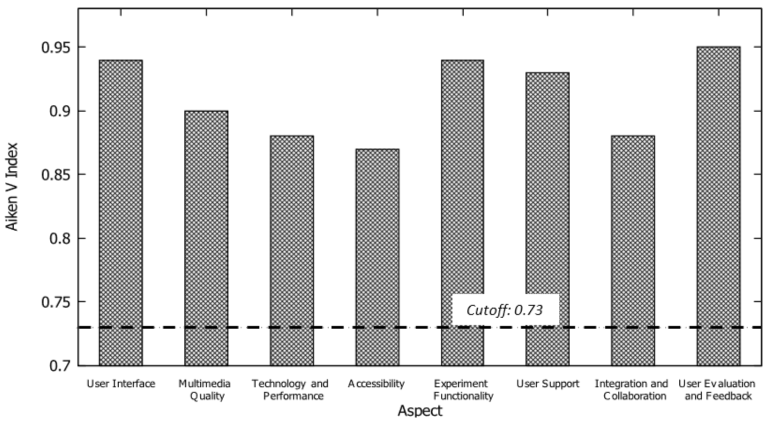

Figure 4. Media expert validation results on PC R-PhyLab

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.

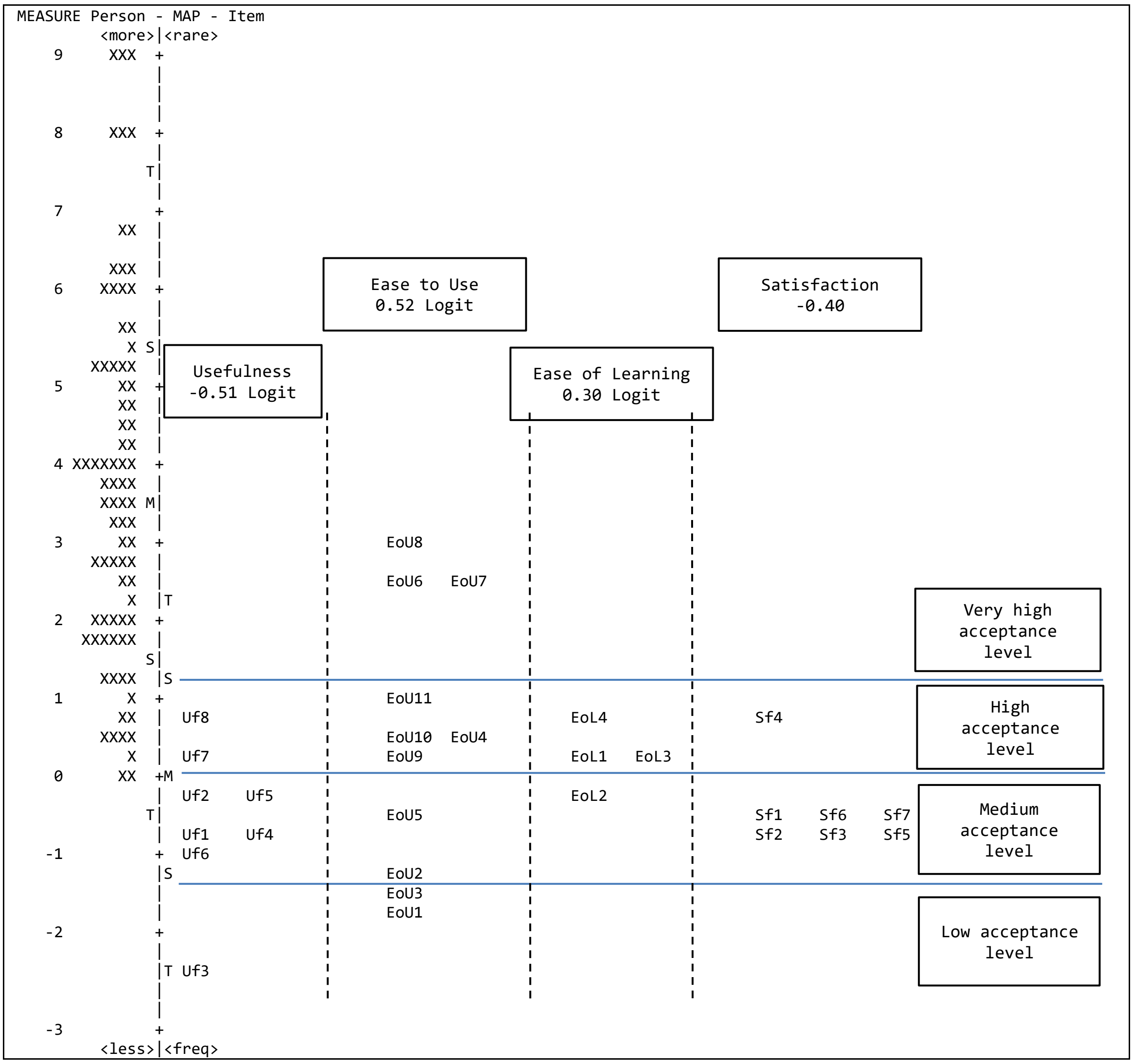

Figure 5. User acceptance level of PC R-PhyLab

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

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
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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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