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Development of Virtual Laboratory in Physics Subject for Senior High School Phase-F

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Abstract: This study aims to develop a valid, practical, and effective virtual laboratory as a solution to overcome limitations in physics education, with the expectation of improving both teaching quality and students' understanding of physics concepts. The research follows a Research and Development (R&D) approach using the 4-D model, which includes four stages: define, design, develop, and disseminate. The subjects of this study were 28 Phase-F students at SMA Negeri 11 Padang. The results include a virtual laboratory for Phase-F high school physics, validated with high scores: 89% for content validity, 97% for media validity, and 92% for language validity, all categorized as highly feasible. The trial for practicality among students scored 80.39%, categorized as practical, while the teacher trial scored 97%, categorized as highly practical. The effectiveness test showed significant improvement in student performance, with the average score increasing from 38.39 to 79.64. The N-gain score was 0.67, indicating moderate improvement. Based on the development and trials, it can be concluded that the virtual laboratory product for Phase-F high school physics is valid, practical, and effective for use in learning activities.

Keywords: Learning media; Physics; Virtual laboratory

Introduction

The rapid advancement of science and technology has driven transformation across various fields, including education. In this digital era, technology not only simplifies daily activities but also plays a significant role in enhancing the quality of learning. Educational technology, as explained by Purba et al. (2023), aims to improve learning processes through digital media. Serving as both an information source and a teaching tool, technology has the potential to increase the efficiency and effectiveness of education, especially in schools (Miasari et al., 2022; Rahmi et al., 2023; Utami et al., 2022). One such application of technology is learning media, designed to convey information in an accessible and interactive manner (Putri et al., 2022; Suppa, 2015; Widiarini et al., 2022). Various hardware and software tools, such as laptops and videos, are used as aids for teachers in delivering instructional materials (Adam et al., 2015). These technologies not only simplify the teaching-learning process but also encourage active student participation, which is often difficult to achieve in abstract subjects like physics (Canlas et al., 2020).

Physics education has unique characteristics and requires a concrete approach to facilitate students' understanding. Ideally, physics laboratories support the learning process by providing facilities for practical experiments, where students can conduct hands-on experiments to test the theoretical concepts they have learned in class (Fatimah et al., 2021; Ristina et al., 2020). However, laboratory usage is often scheduled only at the end of a topic, after the theory has been taught. This limits students' opportunities to understand concepts through practical experience. Yet, a continuous experimental approach can improve students' understanding of abstract topics like mechanics,

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electricity, and waves through direct observation. Laboratory activities should ideally be integrated at the beginning of the learning process, starting with simple experiments and progressing to more complex ones in the development stage, helping students cultivate critical and analytical thinking skills (Qin et al., 2020; Ramadani et al., 2021).

At SMA Negeri 11 Padang, an interview with physics teacher Ms. Riri Rahmatias, S.Si., revealed that the use of the Merdeka Curriculum since 2021 has not been fully supported by the optimal use of appropriate digital learning media. The available media are often conventional, such as textbooks and slide presentations, which, according to research, lack appeal for students (Harahap et al., 2024; Warouw et al., 2024). Initial observations indicate that 70.30% of students struggle with learning physics, and the limited use of media contributes to their low interest in the subject. The use of the physics laboratory is also very limited, only once per semester, which means students do not have sufficient opportunities to conduct experiments and understand concepts deeply. Limited resources in the laboratory, both in terms of time and equipment, pose additional challenges (Hanidar et al., 2024; Ilyas et al., 2022; Samiasih et al., 2013).

Interactive learning media, such as virtual laboratories, can serve as a solution to these limitations. A virtual laboratory allows students to perform experiments in a digital simulation that resembles a real laboratory, accessible anytime without requiring physical equipment. Virtual laboratories provide an experience similar to being in an actual laboratory, with complete simulations of laboratory (Mahzum et al., 2024; Rahmatullah et al., 2023; Sari et al., 2022; Wahyuni et al., 2021; Zhang et al., 2023). Research indicates that virtual laboratories can enhance students' understanding of physics concepts, as well as offer them the freedom to repeat experiments that may be difficult to conduct in physical labs (Gunawan et al., 2017; Mahzum et al., 2024; Sanggara et al., 2018; Thaariq et al., 2023). Additionally, software such as Adobe Animate enables the creation of accessible and visually engaging interactive simulations, making the learning process more effective.

Based on the issues at hand, this study aims to develop a virtual laboratory as a physics learning medium for high school students in Phase-F. This virtual laboratory is expected to serve as an effective alternative to support physics education, with features that allow students to conduct digital, independent experiments. Consequently, this virtual laboratory is expected to enhance the quality of physics instruction, facilitate student access to experiments, and address the limitations encountered in conducting physics practicums in conventional laboratories.

Method

This study uses the Research and Development (R&D) method with the 4-D model by S. Thiagarajan, which includes the stages of defining (initial analysis, student evaluation, and formulation of learning objectives), designing (creation of tools, selection of materials, and product design), development (expert evaluation and trials), and dissemination (implementation of the product in classroom and other school environments). Each stage in this model is part of a continuous process aimed at producing a valid, practical, and effective final product: a virtual laboratory for Phase-F high school physics. The development process is illustrated in the diagram in Figure 1.

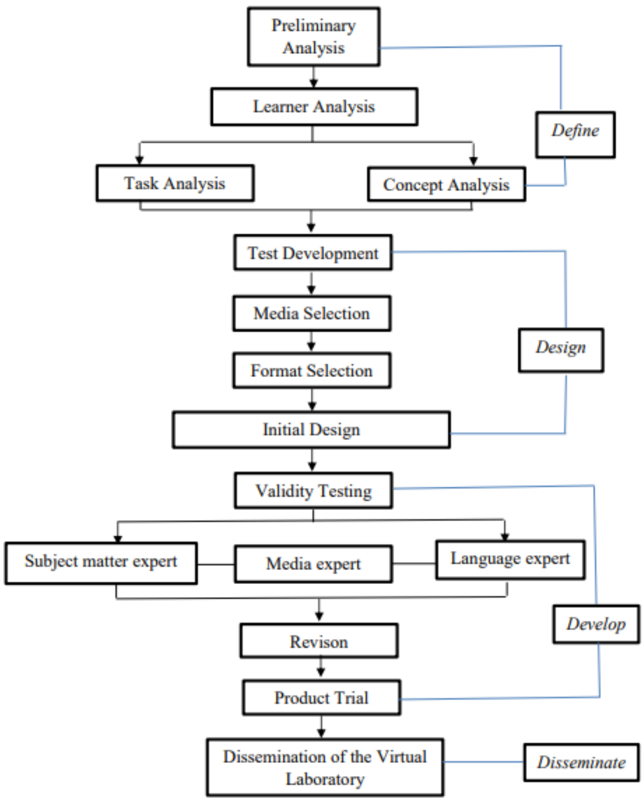

Figure 1. 4-D model development procedure

Based on Figure 1, it can be seen that the Definition Stage in the development of a virtual laboratory for motion kinematics includes several key steps. First, a preliminary analysis is conducted to identify issues related to the use of conventional media in physics learning and the limitations in conducting laboratory practicums. Interviews with physics teachers at SMA Negeri 11 Padang confirmed the need for a virtual laboratory medium to address these limitations. Next, an analysis of learners is conducted to understand student characteristics and adapt the instructional media to meet their needs. Task analysis ensures that all learning tasks align with the established objectives, aiding in the evaluation and adjustment of content. Finally, concept analysis identifies and organizes key concepts so that the virtual laboratory media can be presented interactively to optimally support student learning.

The design stage in the development of a virtual laboratory for physics learning, particularly on the topic of motion kinematics, includes establishing test standards to assess students' abilities, selecting media that match student characteristics and motion kinematics content, and choosing a format based on previous research designs. The initial design of this media, created using Adobe Animate, combines visuals, text, and animation to create an interactive and easily understandable virtual laboratory aligned with the guidelines for Senior High School Physics, Phase-F.

The development stage in creating the virtual laboratory media involves refining the product design, validation, and testing. Validation is carried out by a team of subject matter, media, and language experts to evaluate and improve the product based on their feedback. Subsequently, the product is tested in two stages: practicality testing to ensure ease of use and efficiency, and effectiveness testing to assess the media's impact on enhancing student learning outcomes, measured through a comparison of pre-test and post-test results.

The dissemination stage in the Thiagarajan model (1974) includes three steps: validation testing, packaging, and diffusion and adoption. In validation testing, the revised product is tested with the target audience to measure its effectiveness. Then, the product is packaged for easy access by teachers and students, such as through a Google Drive link. The final step is diffusion and adoption, where the product is disseminated, allowing both teachers and students to access and comprehend the material provided through the virtual laboratory.

Research Subject

The purpose of this research is to improve students' academic achievement in Physics Phase-F at SMA Negeri 11 Padang by supporting the development of virtual laboratory learning media. The participants of this study are 28 students from Phase-F at SMA Negeri 11 Padang.

Data Collection Technique

This research used data collection techniques in the form of interview sheets and questionnaires.

Data Analysis Technique

The data analysis technique used is purposive collection, which results in two types of data: qualitative and quantitative. Qualitative data is obtained from evaluations and feedback provided by instrument validators, media validators, material validators, and language validators. This data is then compiled together to make improvements to the product being developed. Quantitative data is obtained through questionnaire responses from instrument validators, media validators, material validators, language validators and practicality test. Data analysis is conducted using descriptive statistics. The range of assessment categories can be seen in Table 1.

Table 1. Score Interpretation Criteria (Riduwan, 2012)

Presentase (%)	Categor
81-100	Very valid/very practica
61-80	Valid/practica
41-60	Quite valid/quite practica
21-40	Not valid/not practica
0-20	Very invalid/very impractica

To calculate the percentage of each sub-variable using the formula in Equation 1 below.

$$P(s) = \frac{S}{N} x 100\% \quad (1)$$

Explanation
P(s) : Percentage of score
S : Total score for each sub-variable
N : Maximum total score
At the stage of data analysis, an effectiveness test of the media is also conducted.

Effectiveness Test

Normalized gain, or N-gain score, aims to determine the effectiveness of using a specific method or treatment in research. The N-gain score test is performed by calculating the difference between the pretest and posttest scores. Calculate the normalized gain score using the formula provided in Equation 2.

$$< g >= \frac{Tf - Ti}{SI - Ti} \quad (2)$$

Explanation
<g> : Normalized Gain
Tf : Post-test Score
Ti : Pre-test Score
SI : Ideal Score
To determine the criteria for gain improvement in the following Table 2.

Table 2. Normalize Gain Value (Sugiyono, 2017)

Normalize gain value	Category
G ≥ 0.7	High
0.3 ≤ g ≥ 0.7	Moderate
G ≤ 0.3	Low

Result and Discussion

Result

The results of this research and development are a virtual laboratory used in physics learning for phase-F students. The development of the virtual laboratory followed the 4-D development model, which consists of four stages. The first stage is Definition, aimed at identifying learning needs through analysis. At this stage, observation questionnaires were distributed to phase-F students at SMAN 11 Padang, and interviews were conducted with a physics teacher to understand the learning challenges faced. The data obtained formed the basis for planning the virtual laboratory.

The second stage is Design, which focuses on designing the virtual laboratory to meet the needs of physics learning. In this stage, an analysis of learning objectives was conducted, appropriate media and formats were selected, and the virtual laboratory product was developed. This design aims to ensure that the developed product can assist students in understanding physics concepts more effectively and interactively.

The third stage is Development, where the designed product is validated by a team of experts, including content experts, media experts, and language experts. This validation ensures that the product meets quality standards in terms of content, visuals, and language. After validation, the product is tested on students to measure the practicality and effectiveness of the virtual laboratory in the learning process. The results from validation and practicality tests are used to refine the virtual laboratory before it is marketed or disseminated to the next stage.

Table 3. The Results of the Material Validation

Criteria variable	Assessment
Scope of material	13
Presentation of material	14
Up-to-dateness and contextual relevance	12
Authenticity of material	5
Scientific skills	14
Function of material in virtual laboratory content	9
Total	67
Percentage	89%
Criteria	Highly valid

Table 4. The Results of the Media Validation

Criteria variable	Assessment
Artistic and aesthetic	23
Program management	15
Overall function	20
Total	63
Percentage	97%
Criteria	Highly valid

After the material validation results were deemed highly feasible, the next step was to validate the media, which was assessed by media experts, as shown in Table 4. After the media validation results were deemed highly feasible, the next step was to validate the language, which was assessed by language experts, as shown in Table 5.

Table 5. The Results of the Language Validation

Criteria variable	Assessment
Compliance with language rules	9
Sentence appropriateness	18
Suitability for students	28
Total	55
Percentage	92%
Criteria	Highly valid

After validation, the developed media is deemed suitable for use and is tested to assess its practicality, with the results as follows.

Table 6. Results of Student Practicality Trials

Criteria variable	Assessment
Ease of use	537
Material presentation	347
Display	537
Benefits	450
Total	1907
Percentage	80.39%
Criteria	Practical

Based on Table 6, the results of the practicality questionnaire, which includes four criteria, ease of use, material presentation, appearance, and benefits, show that the virtual physics laboratory for SMA Phase-F received a total score of 1907 with a percentage of 80.39%, which falls into the practical category. This result was obtained from 28 students who participated in the practicality test.

Effectiveness Test

Table 7. N-Gain Test Results

Information	Pre-test	Post-test
Amount	1075	2230
average	38,39	79,64
N-gain		0,67
N-gain percentage		66.73%
Category		Currently

The effectiveness test of the media was conducted using pretests and posttests involving 28 students at SMA Negeri 11 Padang to measure initial knowledge and the improvement in understanding after using the virtual laboratory. Students were given access to explore the virtual laboratory before taking the posttest with 20 objective questions. The results of the pretest and posttest show changes in students' understanding levels. The N-gain results can be seen in Table 7.

Discussion

The purpose of this research is to create a virtual laboratory for high school physics (Fase-F), focusing on the components of straight motion kinematics (uniform motion, uniformly accelerated motion, and free fall motion). This virtual laboratory, developed using Adobe Animate, aims to assess the relevance, practicality, and effectiveness of the learning process. The results indicate that the virtual laboratory application is highly interactive and user-friendly, stored in an executable (.exe) format, allowing students to run it on their computers or laptops without needing any installation. In line with this, the .exe format was chosen to ensure the application is easily accessible and functions optimally in various computer environments, especially in classrooms or school laboratories (Faour et al., 2018; Maulidah et al., 2018; Mihret et al., 2022). After validation by experts, the media was deemed suitable for use, receiving high ratings in terms of artistic aspects, program management, and overall functionality.

This study followed a four-stage development model consisting of definition, design, development, and dissemination. Needs analysis and product design, including flowcharts and storyboards, were conducted in the design phase. Expert validation was performed to ensure product quality. A trial with Fase-F students from class F-7 at SMA Negeri 11 Padang demonstrated that the virtual laboratory is easy to use and effective in enhancing student understanding. In line with the research conducted by Ilyas, the use of virtual laboratories is effective in improving students' conceptual understanding (Adanır et al., 2022; Arista et al., 2018; Falode et al., 2017). Students indicated that the media is easy to use, beneficial, and helps more students grasp the concepts of straight motion kinematics.

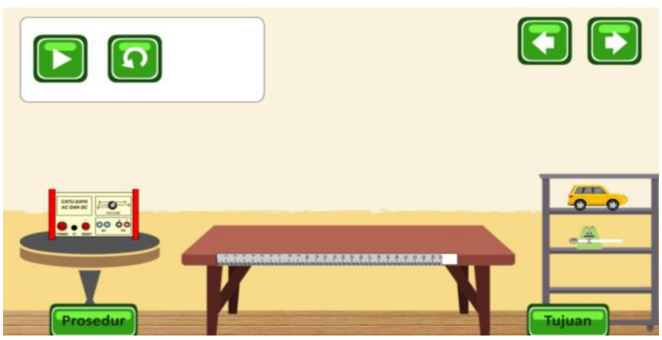

Figure 2. Example of experiment in virtual laboratory learning media

In the final stage, dissemination, the virtual laboratory was provided to physics teachers at high schools in Padang. According to teacher surveys, the virtual laboratory was rated as practical, with a 61% score. The media was considered effective in meeting the learning objectives for high school physics in Fase-F. The laboratory was distributed via a Google Drive link, making it easily accessible and usable by both teachers and students, and is expected to replace physical classroom practices and improve students' understanding of physics concepts.

Conclusion

This research produced a virtual physics laboratory for high school Phase F using the 4D development model (define, design, development, disseminate), which was deemed highly suitable after validation of its instruments, content, media, and language. Survey results from teachers and students demonstrated the laboratory's practicality, showing it is easy to use and provides an efficient learning experience with clear instructions. Effectiveness tests using pretest and posttest indicated a significant improvement in students' understanding of Uniform Linear Motion (GLB), Accelerated Linear Motion (GLBB), and Free Fall (GJB), confirming that this medium is effective in physics education.

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Author Contributions

Conceptualization, methodology, M. R. Z. R. F. J.; validation, A. U. Y. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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