Development 3D Virtual Laboratory the Hertz Experiment on the Topic of Sound and Light Waves

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Abstract - *This study is development research aimed at determining the validity, practicality, and effectiveness of 3D virtual laboratory media for the Hertz experiment on sound and light wave material. The research sample consisted of 30 eleventh-grade students from the Digital Class of MAN 2 Bone. The method used was Research and Development (R&D) following the ADDIE model (Analyze, Design, Develop, Implement, Evaluate). The results showed that the media was declared highly valid by physics learning media experts based on the Gregory test. The media's practicality received ratings of 97.35% from the physics teachers and 82.08% from students, both classified as very practical, indicating its high efficiency in the classroom. Furthermore, the N-gain test on students' interest in physics yielded an average score of 0.49. This indicates a moderate yet positive enhancement in students' learning engagement. Therefore, this 3D virtual laboratory is proven to be a highly practical, valid, and engaging instructional medium that successfully supports the visualization of abstract physics concepts.*

Keywords*: Learning Media; Virtual Laboratory; Hertz Experiment*

INTRODUCTION

Physics learning is an important part of the education curriculum that offers an understanding of natural phenomena and fundamental principles in science. However, many students face difficulties in grasping the abstract and complex concepts of physics. A deep understanding of physics requires more than just reading texts or listening to teacher explanations. Students also need practical experiences and concrete visualizations to comprehend these concepts (Kelly and Finlayson, 2007).

Practical experience, such as conducting experiments, enables students to directly observe physical phenomena, analyze results, and draw conclusions. Typically performed in school laboratories, these experiments provide critical hands-on learning opportunities. Learning media, as provided by teachers during instruction, serve as essential tools to visualize and simulate these concepts effectively.

The legal framework, including Undang-Undang Number 14 of 2005 on Teachers and Lecturers and Permendiknas Number 16 of 2007 on Academic Qualification Standards and Teacher Competencies, mandates that teachers must competently utilize information and communication technology in their teaching and employ learning media suited to student characteristics and subject matter to achieve educational objectives fully.

The 21st century marks an era defined by knowledge, information technology, globalization, and the Fourth Industrial Revolution. Integrating technology into education drives numerous innovations, particularly in learning media (Rosnaeni, 2021). Physics, which requires hierarchical and interconnected conceptual understanding, often suffers from student disengagement and passivity, adversely affecting learning outcomes (Supardi et al., 2012). Therefore, employing appropriate media is crucial to rendering physics comprehensible and engaging.

Virtual laboratory learning media is one of the flagship products created from technological advances. The implementation of virtual laboratories can be defined as an interactive environment for creating and conducting simulation experiments (Ramadhani et al., 2021). On the other hand, Virtual Reality (VR) technology has rapidly developed, offering immersive and interactive experiences that allow users to interact with digital environments in real-time. In the context of learning, VR has great potential to enhance the understanding of physics concepts by enabling students to directly experience physical phenomena, even within a virtual environment.

The development of this media specifically focuses on the Hertz experiment due to its crucial role in demonstrating electromagnetic wave phenomena. As highlighted in the early history of electromagnetic waves (Sengupta & Sarkar, 2003). Heinrich Hertz's experiment was fundamental in translating James Clerk Maxwell's purely mathematical theories into observable physical reality. For high school students, Maxwell's concepts of wave propagation often appear mathematically intimidating and visually inaccessible. By digitally reconstructing Hertz’s transmitter apparatus in a 3D environment, this media provides students with a direct visual confirmation of invisible electromagnetic properties.

Observations at MAN 2 Bone showed that physics teaching relies too much on textbooks because no physics experiments are conducted due to limited class time from additional religious subjects. This situation requires innovative media to simplify abstract concepts for students. Because there is currently no 3D virtual laboratory for the Hertz experiment, this research develops a new prototype. As an initial Research and Development (R&D) phase, this study focuses on evaluating the media's validity, practicality, and its impact on student interest.

From a theoretical perspective, the integration of 3D virtual media aligns with the principles of the Cognitive Theory of Multimedia Learning (Mayer & Fiorella, 2021). According to this framework, well-designed interactive instructional media can help minimize extraneous cognitive load. In the context of the abstract Hertz experiment, a 3D virtual reality environment facilitates the processing of complex visual and spatial information, which helps mitigate the cognitive barriers frequently encountered in conventional textbook-based learning.

RESEARCH METHODS

The research method used is the research and development method, or Research & Development (R&D). This method is employed to produce a product and test the effectiveness of the product in accordance with the development objectives (Nurmasitah et al., 2017).

This research was conducted in the even semester of the 2024/2025 academic year. The research took place from May 19, 2025, to May 23, 2025. The trial location was in the 11th-grade Digital class at MAN 2 Bone, located on Jl. Yos Sudarso, Tanete Riattang District, Bone Regency, South Sulawesi Province.

The development model used in this research on developed learning media is the ADDIE model. ADDIE stands for the instructional system development process, which includes Analysis, Design, Development, Implementation, and Evaluation (Pratama et al., 2019).

The product produced in this research is a 3D virtual laboratory media for the Hertz experiment. The trial process was conducted through several stages, which are:

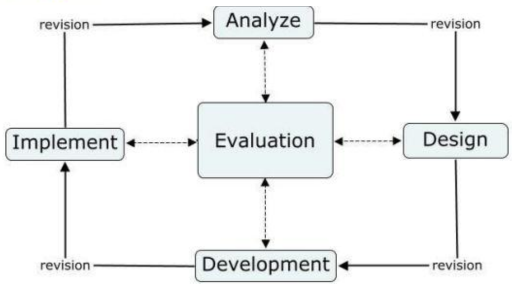


Figure 1. Flow of the ADDIE Development Model

The product validation is conducted by involving media experts and subject matter experts to validate the developed product, as well as to provide suggestions and feedback for evaluation purposes (Purnama, 2013). At this stage, the developed product will also undergo validity testing based on following table:

Table 1. Validity Criteria

Validity	Validity Score
Highly Valid	4
Valid	3
Less Valid	2
Invalid	1

(Gregory, 2015)

The validation instrument assesses the product design based on expert feedback, using a validation sheet to score aspects like material suitability, physical phenomena representation, and content feasibility, rated on a Likert scale (Table 1). Then, the analysis technique used is based on the evaluation of two experts using Gregory's formula in the following table.

Table 2. Gregory Formula

Tabulation Result		Expert 1	
		Score 1 - 2 (Irrelevant)	**Score 3 - 4 (Relevant)**
Expert 2	Skor 1 - 2 (Irrelevant)	**A**	**B**
	Skor 3 - 4 (Relevant)	**C**	**D**

The calculation for the validity results of two experts uses Gregory's formula as follows:

$$(V) = \frac{D}{A+B+C+D} \qquad (1)$$

V is Gregory's internal consistency coefficient.

The implementation phase was carried out through a limited field trial involving 30 eleventh-grade students from the XI Digital Class of MAN 2 Bone. This implementation process was allocated for a duration of 3 lesson hours (3×45 minutes). During this session, the students were divided into small groups and provided with Student Worksheets (LKPD), VR Cardboards, and controllers. Using the 3D virtual laboratory, the students were instructed to actively perform the Hertz experiment by manipulating and varying different wave frequencies. The observation data were then recorded systematically in the LKPD and compared with the speed of light constant (*c*) found in their physics textbook.

Product assessment data by teachers and students, a questionnaire instrument is used to determine the responses of teachers and students to the developed media. The steps for analyzing the responses of teachers and students are as follows. (a) Practicality analysis, the practicality analysis aims to assess the extent to which the developed product can be considered practical. This assessment is conducted through a questionnaire completed by physics learning teachers and students.

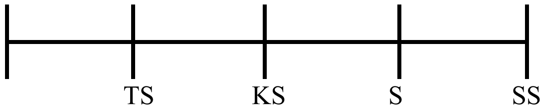
Table 3. Scoring Criteria for Media Practicality Assessment

Validity Level	Score
Strongly Agree	4
Agree	3
Less Agree	2
Disagree	1

(Sugiyono, 2013)

To determine the overall tendency of student responses, the total score obtained from each statement is required. Then, on a continuum, it can be categorized as shown in the following table:

Table 4. Categorization of Student Response Tendencies



Explanation: (SS) Strongly Agree, (S) Agree, (KS) Less Agree, (TS) Disagree

(Sugiyono, 2013)

Then, the calculation of the media practicality percentage (xi) is carried out using the following equation:

$$xi = \frac{\text{Total score}}{\text{Maximum Score}} \times 100\% \quad (2)$$

Then, the average practicality percentage value is calculated to represent the practicality value using the formula:

$$\text{Practicality Value } (P) = \frac{\Sigma xi}{n} \times 100\% \quad (3)$$

Next, convert the values from quantitative data to qualitative data using the following Table 5:

Table 5. Practicality Value Conversion

Percentage value (%)	**Response**
0-20	Very Impractical
21-40	Impractical
41-60	Quite Practical
61-80	Practical
81-100	Very Practical

(Riduwan, 2010)

Effectiveness analysis measures improvement using the N-gain index, calculating the increase in students' interest in physics before and after using 3D virtual lab media for the Hertz experiment. The N-gain is calculated using the following equation:

$$\text{N-gain} = \frac{\text{Postest score - Prestest score}}{\text{Maximum score - Pretest}} \quad (4)$$

Then, to determine the effectiveness level of the learning media, the average N-gain score is calculated for each respondent then categorized the average by using following equation and table:

$$\text{Average N-gain} = \frac{\Sigma \text{ N-gain}}{\text{respondent}} \quad (5)$$

Table 6. N-gain Categorization Guidelines

Range	Category
$g > 0.7$	High
$0.3 \leq g \leq 0.7$	Medium
$g < 0.3$	Low

(Handayani et al., 2019)

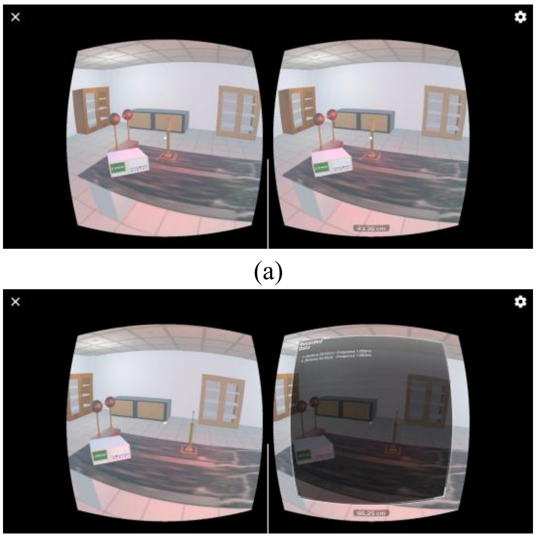
RESULTS AND DISCUSSION

The research and development results are a 3D virtual laboratory media for the Hertz experiment on the topic of sound and light waves. The development of this virtual laboratory used the ADDIE model, which consists of five stages, including (1) Analyze; (2) Design; (3) Development; (4) Implement; and (5) Evaluation.

The first stage is analyse stage, a needs assessment was conducted at the MAN 2 Bone. Interviews with physics teachers revealed that physical experiments were often skipped due to limited class time, as the school allocates a significant portion of its schedule to religious subjects. To address this issue, the design stage focused on creating a storyboard and user interface to accurately simulate the Hertz wave experiment in a virtual environment.

During the development stage, the 3D visual objects were created using Blender 4.4, while the interactive simulation was built using Unity 6. This stage also included an iterative validation process by media experts. Based on their feedback, a real-time data recording panel was added to the system, allowing users to save their measurement results directly within the simulation.

This media was successfully developed as an interactive simulation environment that computationally visualizes the phenomena of electromagnetic waves. Technically, the architecture of this product was built using Unity 6, which is designed to convert mathematical wave models into real-time visual representations. The main simulation interface, as presented in Figure 2.



(a)

(b)

Figure 2. Visual representation of the simulation in VR mode: (a) the interactive environment for manipulating frequency and receiver position during data collection; (b) the data logging interface presenting the recorded experimental results.

Figure 2 demonstrates a precise virtual laboratory space where users can dynamically manipulate frequency and receiver's position to interact directly with the fundamental physical parameters of the waves.

Within this interactive setup, the abstract nature of electromagnetic wave propagation is translated into observable empirical data. When students adjust the transmitter's frequency and spatially move the receiver, they can observe real-time visual feedback: the receiver illuminates brightly at the wave's peaks and dims at the nodes. This specific mechanism allows users to accurately identify and measure the wavelength. By multiplying this measured wavelength with the manipulated frequency, students can calculate the speed of light. This underlying physical modeling ensures that the media functions not merely as a passive visual animation, but as a robust analytical instrument that facilitates high-level conceptual understanding and quantitative measurement.

The validity of the developed 3D virtual laboratory was evaluated by two expert validators who assessed both the instructional media design and the accuracy of the physics content. The detailed assessment results, as presented in Table 7, were analyzed using the Gregory test, resulting in a validity coefficient (V) of 1.00, which exceeds the standard consistency threshold of 0.75. This strong agreement between the experts indicates that the computational modeling, user interface, and physical concepts of electromagnetic wave propagation within the simulation are accurate and free from technical or conceptual errors. Therefore, the media is considered highly valid and ready for implementation in the classroom.

Table 7. Media Validation Result

Indicator	Validator I	Validator II
Instructional Feasibility	27	26
Software (Technical Reliability)	20	21
Visual Design	20	20
Total	67 (93.1%)	67 (93.1%)

After the media was declared technically valid, the implement stage was carried out through a field trial involving 30 students and 2 physics teachers. The students worked in groups, using VR Cardboards and controllers to perform the virtual experiment. Finally, in the evaluation stage, empirical data was collected using questionnaires to measure the media's practicality from both teacher and student perspectives, as well as its preliminary effectiveness on students' learning interest.

The practicality of the 3D virtual laboratory was evaluated through user response questionnaires administered to a physics teachers and students. The evaluation results, as presented in Table 8. This high level of practicality indicates that the media is easy to operate, provides clear user instructions, and requires minimal technical preparation before classroom use.

Minimizing preparation time is particularly beneficial for schools with constrained instructional schedules. These findings align with Syefrinando et al. (2020), who stated that interactive 3D learning media with high practicality ratings can streamline teaching time and simplify the presentation of abstract physics concepts. Consequently, the developed media meets the required practicality standards for integration into high school physics classrooms.

Table 8. Product Practicality Evaluation Results

Respondent	Practicality	Cateogory
Physics Teacher	97.35%	Very Practical
Students	82.08%	Very Practical

The high practicality ratings (97.35% from the teacher and 82.08% from students) show that the 3D virtual laboratory is highly efficient for classroom use. According to the Cognitive Theory of Multimedia Learning (Mayer & Fiorella, 2021), instructional media should be designed to manage cognitive load effectively. The 3D virtual laboratory applies this principle by integrating interactive visualizations directly with a real-time data recording panel, which successfully minimizes extraneous cognitive load and prevents the split-attention effect. This is consistent with Achuthan et al. (2015), who found that multimedia virtual labs reduce the perceived difficulty of physics experiments.

Moreover, the practical benefit of this media aligns with findings by Fernando et al. (2024), where 76% of users favored virtual labs for their high repeatability. This feature allows students to freely manipulate variables and repeat the Hertz experiment without the risk of damaging equipment or running out of limited class time. Conclusively, this developed media serves as a practical solution that effectively supports physics learning within constrained school schedules.

During the implementation phase, the main constraint encountered was hardware compatibility, as some students used iOS devices while the application was developed exclusively for Android. Additionally, the virtual laboratory requires a responsive gyroscope and Bluetooth 5.0 for seamless controller synchronization. To address this issue, student groups were strategically adjusted during the field trial to ensure that each team had access to at least one fully compatible Android device.

The effectiveness level of the learning media was obtained through a survey method using questionnaires related to students' interest in learning physics before and after applying the learning media during the learning process. The questionnaire results were then analyzed to determine how effective the 3D virtual laboratory media is in increasing students' interest in learning physics. To measure the media's effectiveness in enhancing students' interest in learning physics, an N-gain (Normalized Gain) test was conducted. This test compares students' interest scores before and after using the 3D virtual laboratory media for the Hertz experiment.

This study is limited to evaluating the affective domain, specifically students' interest in physics, which demonstrated a moderate N-gain (0.49). Cognitive learning outcomes and conceptual understanding were not assessed. Consequently, future research should investigate the impact of this 3D virtual laboratory on cognitive achievements and conduct broader empirical testing to establish its pedagogical efficacy fully.

CONCLUSION

The 3D virtual laboratory for the Hertz experiment has been successfully developed using the ADDIE model. This media provides a highly valid and practical solution to help students visualize abstract electromagnetic wave concepts, making it highly suitable for schools with limited physics laboratory schedules. Furthermore, the field trial demonstrates that the immersive simulation successfully gives a positive impact on enhancing students' learning interest. Since this research is specifically limited to media development, future studies are recommended to focus on implementing this tool to evaluate students' cognitive learning outcomes.

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