



# Smartphone Sensor-Based Physics Module for Hands-On Learning in Waves and Optics

Endra Putra Raharja<sup>1\*</sup>, Edi Sutomo<sup>1</sup>, Febrian Andi Hidayat<sup>1</sup>, Asih Kasan<sup>1</sup>, Nia Mangkasa<sup>1</sup>

<sup>1</sup>Science Education Department, Universitas Pendidikan Muhammadiyah Sorong, Indonesia.

Received: December 31, 2024

Revised: February 19, 2025

Accepted: March 25, 2025

Published: March 31, 2025

Corresponding Author:

Endra Putra Raharja

[endra@unimudasorong.ac.id](mailto:endra@unimudasorong.ac.id)

DOI: [10.29303/jppipa.v11i3.10240](https://doi.org/10.29303/jppipa.v11i3.10240)

© 2025 The Authors. This open access article is distributed under a (CC-BY License)



**Abstract:** The limited laboratory equipment in many schools hinders students in conducting physics experiments, so that learning is more theoretical and less supportive of practice-based understanding. This study aims to develop a smartphone sensor-based physics experiment module on wave and optical materials that is valid, practical, and effective, and allows students to conduct experiments flexibly and independently. This research uses the Research and Development (R & D) method with the Borg & Gall model. Validation by media and material experts showed that this module has met the eligibility standards, with a score of 3.67 (73.4%) for media aspects and 3.56 (71.2%) for material aspects. The practicality test showed that this module can be used well in experimental learning, with a score of 3.48 (69.6%) in the "Good" category. Evaluation of effectiveness through comparison of pre-test and post-test showed an increase in learning outcomes with an N-gain of 0.55 (medium category). These results indicate that the integration of smartphone sensors in physics experiments can be an alternative solution for schools with limited laboratory facilities. This module offers a more flexible, accessible and technology-based learning approach. Future research can develop similar modules for other physics materials and evaluate their effectiveness in various learning scenarios.

**Keywords:** Hands-on learning; Module development; Physics education; Smartphone sensors; waves and optics

## Introduction

Physics education at the high school level faces various challenges, one of which is the understanding of concepts that are less clear and not well organized, causing difficulties in the learning process (Tuzón & Solbes, 2016). This problem is further exacerbated by the lack of practicum activities, even though practicum has an important role in helping students connect theory with practice (Moeed, 2013). Without adequate practicum experience, many students only understand physics superficially, which ultimately limits their conceptual understanding (Kurniawan et al., 2019). Research shows that the application of inquiry-based learning supported by technology can improve students' problem-solving skills, understanding of physics

concepts, as well as scientific thinking (Kiraga, 2023). Therefore, the use of digital tools in physics experiments can be a solution to strengthen students' understanding more deeply.

Physics education in the 3T (Frontier, Outermost, and Disadvantaged) regions of Indonesia faces greater challenges due to the lack of adequate laboratory facilities and experimental equipment. Many schools in these areas have limited and low-quality resources, so experimental results are often inaccurate and understanding of physics concepts is superficial (Raharja, 2024). The absence of essential tools, such as precise measurement instruments, hinders students from conducting experiments independently (Abdulbasit & Mekuria, 2021). In addition, unstable internet access and limited learning media exacerbate

## How to Cite:

Raharja, E. P., Sutomo, E., Hidayat, F. A., Kasan, A., & Mangkasa, N. Smartphone Sensor-Based Physics Module for Hands-On Learning in Waves and Optics. *Jurnal Penelitian Pendidikan IPA*, 11(3), 580-590. <https://doi.org/10.29303/jppipa.v11i3.10240>

the obstacles in physics learning (Baene, 2023). The combination of these resource and infrastructure issues prevents students in remote areas from having a more complete and meaningful physics learning experience (Edokpolor & Dumbiri, 2019; Poo, 2023).

To overcome laboratory limitations, schools can utilize technological advances, one of which is a smartphone as a tool that is easily accessible and widely used by students (Raharja & Kusiana, 2020). Smartphone usage in Indonesia continues to increase, with the number of users reaching 196.71 million in 2019, of which 91% are aged 15-19 years (Musharyadi, 2024). More than 50% of smartphone users in Indonesia are teenagers, making it a potential tool in digital learning (Yulianto et al., 2023). Apart from providing access to various learning resources, smartphones can also improve 21st century skills, such as critical thinking, problem solving, and digital literacy, when effectively integrated in learning (Azizah, 2023; Lukitasari & Murtafiah, 2021; Rahayu, 2024; Tanuwijaya & Tambunan, 2021),

Smartphones are increasingly recognized as effective tools in physics experiments because they have built-in sensors such as accelerometers, gyroscopes, and microphones. These sensors enable more accurate data collection and analysis, thus enhancing the experiment-based learning experience (Sari et al., 2022). For example, the Phyphox app allows students to measure oscillations, investigate motion, and analyze the nature of sound waves in real-time, thus making experiments easier and more precise (Fatmala et al., 2019; Raharja et al., 2024; Wahyudi et al., 2022). Although several studies have explored the effectiveness of smartphone-based physics experiments, most still focus on mechanics concepts and have not specifically evaluated their impact on students' critical thinking skills (Monteiro et al., 2015; Raharja & Ishafit, 2021; Vogt & Kuhn, 2012; Yasaroh et al., 2021). In fact, critical thinking skills are very important in learning physics, especially in understanding scientific phenomena and solving problems systematically. Therefore, this study aims to develop a smartphone sensor-based experiment that not only improves concept understanding, but also hones students' critical thinking skills (Ewar et al., 2021; Shakur & Kraft, 2016).

Based on these challenges, this study aims to develop a smartphone sensor-based physics experiment module with a focus on the topic of waves and optics for high school students. This study specifically focuses on developing a module that is valid, practical, and effective in improving student engagement, conceptual understanding, as well as critical thinking skills in physics experiments. The module includes practical experiments related to everyday life, such as analyzing simple harmonic motion using the accelerometer on a

smartphone, measuring the speed of sound with the echo method using a smartphone microphone, investigating the Doppler effect using a sound frequency analysis app, and exploring the principle of sonar through sound wave reflection experiments.

Previous research has shown the effectiveness of smartphone sensor-based experimental modules, especially in mechanics topics. For example, (Nurfadilah, Ishafit, Herawati, & Nurulia, 2019) developed a smartphone-based physics experiment guide for collision material, which proved to be valid and well received by students. Similarly, Ariyansah et al. (2021) studied e-worksheets (e-LKPD) based on discovery learning on simple harmonic motion material and found an increase in students' concept understanding. However, most of the previous studies still focus on mechanics experiments and have not developed experimental modules on waves and optics comprehensively.

The novelty of this study lies in the development of a smartphone-based physics experiment module that specifically examines wave and optical phenomena, including simple harmonic motion analysis, sound speed measurement, the Doppler effect, and the sonar principle. In addition, this study also investigates how the use of smartphone technology can improve students' critical thinking skills, something that has not been a major focus in previous research. By utilizing easily accessible smartphone sensors, this module not only expands the scope of physics experiments but also offers an innovative solution to overcome laboratory limitations, as well as helping students develop higher-order thinking skills in physics learning.

## Method

This study used the Research and Development (R&D) method with the Borg & Gall model, which consists of ten systematic stages to design and improve educational products (Puslitjaknov, 2008), as shown in Figure 1. The Borg & Gall model was chosen because it has a comprehensive and iterative approach, enabling the systematic design, development and evaluation of educational programs and products. Compared to other models such as ADDIE or Dick & Carey, the Borg & Gall model offers a more detailed framework for validation and field testing, ensuring a high level of feasibility and effectiveness in the final product (Abdelaziz, 2014; Rahardjanto & Husamah, 2022). This approach ensures that interventions are tailored to specific needs, improving consistency, efficiency and overall effectiveness.

The stages of developing this module include: (1) Initial data collection, to identify the challenges faced by

students and teachers in conducting physics experiments; (2) Planning, which includes designing the structure of the smartphone sensor-based experimental module; and (3) Initial product development, which involves initial trials to develop a prototype of the module.

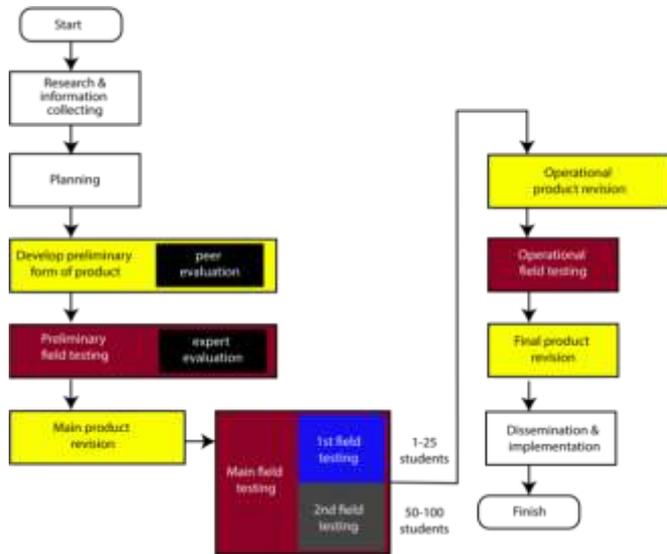


Figure 1. The development steps

This development process is continuously evaluated and refined through subsequent stages: (4) Preliminary Field Testing involves material experts and media experts to assess the validity of the module and identify aspects that need improvement. In this study, five validators were selected based on their expertise in physics education and instructional media development. The selection of five validators was based on the need for an effective and focused evaluation, ensuring diverse yet manageable feedback. Additionally, time and resource constraints were key considerations in determining the number of validators, allowing the validation process to be conducted optimally without compromising the quality of the assessment. Quantitative data analysis was based on questionnaire responses from material experts and media experts. The average score was calculated using Formula 1.

$$\bar{x} = \frac{\sum x}{n} \tag{1}$$

where  $\bar{x}$  represents the average score,  $\sum x$  is the total score, and  $n$  is the number of questions.

The average score was then converted to a percentage using:

$$P = \frac{\bar{x}}{N} \times 100 \tag{2}$$

where  $P$  is the percentage,  $\bar{x}$  is the average score, and  $N$  is the maximum score that can be achieved. The percentage results were evaluated using the criteria in Table 1.

Table 1. Feasibility Level Criteria

Interval (P)	Feasibility Level Criteria
80% - 100%	Very feasible / Very good / Strongly agree
66% - 79%	Feasible / Good / Agree
56% - 65%	Less feasible / Less good / Less agree
0 - 55%	Not feasible / Not good / Disagree

The feasibility of the media is determined based on scores from material experts, media experts, and student responses. A percentage within 80%-100% is classified as "very feasible," while 66%-79% is deemed "feasible" (Arikunto & Cipi Safruddin A.J, 2009).

The next stage (5) Main product revision is performed to improve the module. The revised version is then tested in classrooms during the (6) Main field testing phase, involving 25–50 students. This sample size was chosen using purposive sampling to include students with varying levels of physics proficiency, ensuring the module's effectiveness across different competency levels. The range of 25–50 students is considered optimal because it provides a sufficient number of participants to generate meaningful insights while keeping the data collection and analysis manageable. Additionally, this number reflects typical classroom sizes, allowing for a realistic evaluation of the module's usability in actual teaching and learning environments.

Stage (7) Operational product revisions are made based on results from this broader testing phase, followed by (8) Operational field testing to evaluate the module's effectiveness in standard classroom conditions. To calculate the effectiveness of the product, the n-gain formula is used. The calculation for the effectiveness of the smartphone sensor-based physics experiment guide using the sports vehicle is:

$$g = \frac{\text{posttest value} - \text{pretest value}}{\text{maximum value} - \text{pretest value}} \tag{3}$$

The n-gain value is interpreted based on the following criteria: High, if  $g \geq 0.7$ ; Moderate, if  $0.7 > g > 0.30$ ; Low, if  $g \leq 0$  (Donna et al., 2021)

Validity and reliability of the module were further analyzed, particularly concerning Average Variance Extracted (AVE) values. It was found that some AVE values were below 0.5, indicating potential issues with convergent validity. This suggests that additional refinements in question items and factor loadings might be necessary to strengthen construct validity. Future revisions will address this concern by re-evaluating

measurement instruments and refining module content based on expert recommendations.

Stage (9) Final product revisions refine the module to ensure quality and usability. Finally, (10) Dissemination ensures the completed module is distributed and implemented widely to maximize its impact on physics education. This structured approach ensures that the resulting product is valid, practical, and effective in addressing educational.

## Result and Discussion

### Needs Analysis of Smartphone Sensor-Based Physics Experiment Module

At the needs analysis stage, researchers conducted a problem analysis and student needs survey. The results of the problem analysis showed that limited physics experimental equipment in some schools hindered optimal wave and optics practicum activities. The results of the student needs survey, based on responses from 80 high school students in Sorong Regency, are shown in Figure 2.

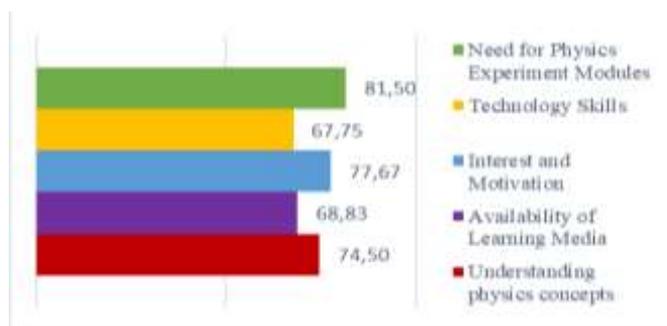


Figure 2. Percentage of Student Needs for Smartphone Sensor-based Physics Experiment Modules

Based on the average scores of the five indicators in Figure 2, students show a high need for technology-based physics experiment modules, especially on the topic of waves and optics. The Module Needs indicator scored the highest at 81.50, indicating the need for interactive and supportive learning materials. Interest and Motivation also scored well at 77.67, reflecting students' enthusiasm for innovative learning methods. However, lower scores in Media Availability (68.83) and Technology Skills (67.75) indicate challenges in access to learning resources and students' ability to utilize existing technology.

### Smart Phone Sensor-based Physics Experiment Module Design

The design of a physics experiment module utilizing smart phone sensors to improve learning efficiency and effectiveness is designed by providing clear instructions to help students understand the

material. The content of the module is optimized by testing physics topics in Aimas Field, Sorong Regency using playground equipment. Exploration of topics such as simple harmonic motion was conducted as shown in Figure 3.

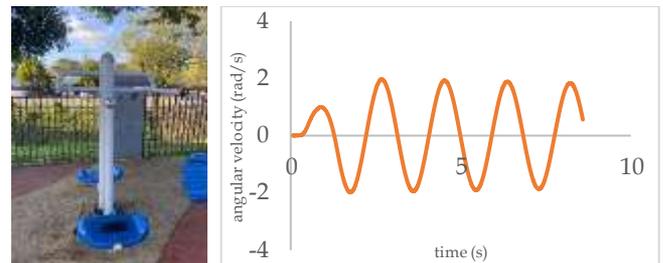


Figure 3. Experiments with smartphone sensors in amusement rides

A draft smartphone sensor-based physics practicum module for wave and optical topics at the high school level was systematically developed to be used as an interactive and applicable experiment guide. The module includes a cover, table of contents, instructions for use, concept map, materials, and practicum activities designed to help students understand physics concepts through technology-based experiments. The image on the module cover (Figure 4) shows the use of smartphone sensors in physics experiments, displaying visualizations of oscillation and wave data that can be measured using special applications. The modern and dynamic cover design reflects the innovative approach to technology-based learning, which combines hands-on experiments with digital data analysis.

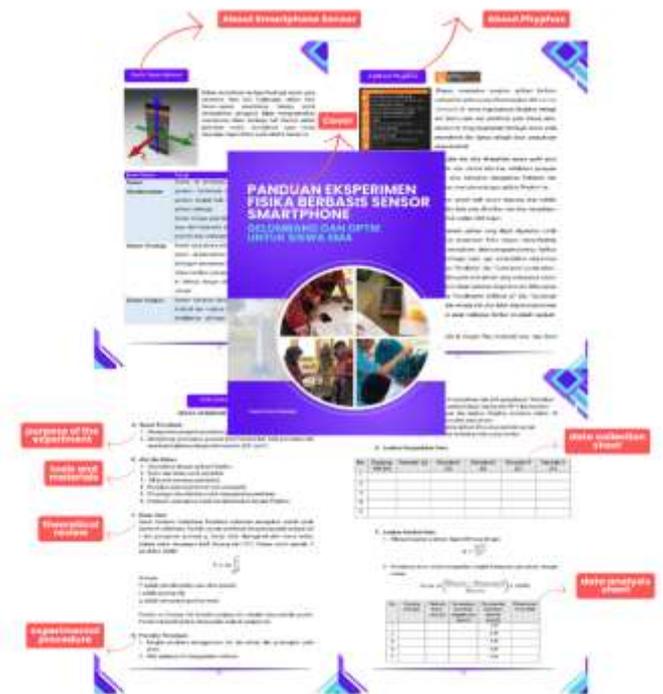


Figure 4. Physics Experiment Module

The structure of this module is made easy to understand by students and teachers, with clear instructions for use regarding experimental procedures and data analysis techniques from smartphone sensors. The concept map in the module provides an overview of the relationship between theory and practice, helping students connect physics concepts with real phenomena. The materials and practicum activities are organized based on the inquiry approach and phenomenon-based learning, allowing students to explore physics concepts more deeply and independently. With this approach, the module is expected to not only improve understanding of physics concepts, but also train critical and analytical thinking skills that are essential in modern science learning.

*Validation of Smart Phone Sensor-Based Physics Experiment Module*

The validity of the smartphone sensor-based physics experiment module was tested through two main aspects, namely media validity and material validity, involving five expert validators. The assessment was conducted using a Likert scale with five indicators, as summarized in Table 2 and Table 3.

**Table 2.** The results from media experts

Indicator	Total Score	Average Score
Design Quality and Appearance of the Module	78	3.9
Format Consistency and Presentation	71	3.55
Readability and Ease of Understanding	73	3.65
Completeness of Media Supporting the Book Module	75	3.75
Efficiency of the Book Media	70	3.5
Average Score (Feasibility Level Criteria)	3.67 (Feasible)	

The results of validation by media experts as in Table 2 show that the smartphone sensor-based physics experiment module has a good level of feasibility with an average score of 3.67 (73.4%), which indicates that this module has met the learning design standards that are suitable for use in the context of physics education. The highest score (78%) was obtained in the “Quality of Design and Appearance” indicator, which indicates that the visual aspects and layout of the module have been developed in accordance with effective instructional design principles (Mayer, 2002).

An attractive design and systematic layout make it easier for students to understand the content of the module, which is in line with the research results who emphasized that visual-based instructional design can increase students' attention and understanding in technology-based learning (Raiyn, J. 2016; Shabiralyani, et al. 2015). The module has also adopted the multimedia

learning principles approach, which emphasizes the use of a combination of text, images, and diagrams to increase the effectiveness of information delivery, as supported by the research of (Mayer & Moreno, 2002).

The efficiency of media use obtained the lowest score (70%), which indicates that there are still some aspects that can be simplified to make the module easier to use in learning. This finding is in line with Rudi & Iskandar, (2022) research which states that digital modules that are too complex or have too much information on one page can hinder learning effectiveness, especially for students who are less familiar with digital devices. Some students and validators reported that the instructions in the module could still be more condensed, and navigation between sections could be made more intuitive.

Therefore, the module could be improved by simplifying the interface, reducing the density of text on a page, and adding navigation icons and a clearer interactive table of contents. In addition, adjustments in the format of presenting experiments with more structured steps and equipped with infographics can improve the efficiency of their use, as suggested in the study of Tong & Pratama, (2023), on the development of technology-based learning media. With these improvements, it is expected that this module is not only more effective in conveying physics concepts, but also more efficient and user-friendly, especially for students who are using smartphone sensor-based experiments for the first time in physics learning. Meanwhile, validation by material experts showed the results presented in Table 3.

**Table 3.** The results from material experts

Indicator	Total Score	Average Score
Relevance of Material to Curriculum	69	3.45
Depth and Accuracy of Material	67	3.35
Ease of Understanding	73	3.65
Relation of Material to Real Life and Technology	71	3.55
Completeness and Support of Material	76	3.8
Average Score (Feasibility Level Criteria)	3.56 (Feasible)	

Table 3 shows the validation by material experts resulted in an average score of 3.56 (71.2%), which indicates that this smartphone sensor-based physics experiment module has met the eligibility standards for use in learning. The highest indicator on the completeness and support of the material (76%) indicates that this module has provided experiments that are quite diverse and relevant to the concepts of wave and optical physics, so that it can help students in understanding the theory through practical applications. The diversity of experiments offered, such as measuring

the speed of sound using a smartphone microphone and investigating the Doppler effect through sound frequency analysis applications, is considered a key advantage as it provides a more in-depth and contextualized inquiry-based learning experience (Etkina et al., 2019).

However, the depth and accuracy of the material obtained the lowest score (67%), indicating that some parts of the module still need to be improved in terms of the complexity of theoretical explanations as well as their connection to real-world phenomena. The lack of recent scientific references supporting the physics concepts explained in the module was also one of the aspects criticized by the validators. This is in line with the finding that the effectiveness of technology-based learning modules is highly dependent on the strength of scientific argumentation and the depth of concept exploration in them (Linn & Eylon, 2011). Therefore, adjustments are needed to enrich the material with actual case studies, experiments based on real problems (problem-based learning), and further integration with deeper physics theory.

As a solution, this module can be improved by adding case studies from experimental research based on smartphone sensors that have been tested in the context of physics learning, such as the research of Yasaroh et al. (2021) which showed that the use of the Phypox application in mechanics experiments can increase student understanding by 78%. In addition, the addition of the context of real-world phenomena, such as the analysis of the Doppler effect in sonar navigation applications on submarines or the use of ultrasonic waves in the medical field, can help students relate the concepts learned to everyday life. These improvements will not only improve the accuracy and depth of the material, but can also increase students' interest in learning physics with an approach that is more applicable and relevant to the development of science and technology.

*Practicality of Smart Phone Sensor-based Physics Experiment Module*

The practicality of the module was tested through a user survey involving 25 students, with five main indicators. The results of the practicality test are summarized in Table 4.

**Table 4.** The results of practicality test

Indicator	Total Score	Average Score
Content	351	3.51
Language	367	3.67
Presentation and Appearance	357	3.57
Clarity of Experiment Instructions	324	3.24
Practicality and Complexity	344	3.44

Indicator	Total Score	Average Score
Average Score (Feasibility Level Criteria)	3.48	(Good)

The practicality test results in Table 4 show that the smartphone sensor-based physics experiment module obtained an average score of 3.48 (69.6%), which is in the "Good" category, so this module can be applied in learning with some improvements. The indicator with the highest score is "Language" (3.67 or 73.4%), which indicates that the use of language in this module is quite easy for students to understand. This is in accordance with the research of Alfa (2023) who found that modules with communicative and less academic language are more easily understood by high school students, especially when explaining abstract concepts in physics such as waves and optics. The "Presentation and Display" indicator also scored quite high (3.57 or 71.4%), indicating that the visual design and structure of the module had been well designed to support readability and user comfort. The study by Ginting et al. (2021) also revealed that multimedia-based modules with a combination of text, images, and interactive instructions are more effective in increasing student engagement in technology-based learning.

The indicator "Clarity of Experiment Instructions" obtained the lowest score (3.24 or 64.8%), indicating that there were obstacles in understanding the experimental procedure by students. Further analysis identified several factors that led to the low score in this aspect. First, the unsystematic steps of the experiment were one of the main causes of students' difficulties in following the sequence of experimental procedures. Some students reported that the instructions in the module were too general and lacked detail, which made it difficult for them to understand the sequence of experiments well. This is in line with the findings of Hofer et al. (2018) who stated that the success of physics experiments is greatly influenced by clear and structured systematic instructions, which allow students to follow step by step without confusion.

Second, the lack of supporting illustrations and schematics was also a significant factor. Although the module included some diagrams and pictures, some students still felt that they needed more detailed illustrations that showed the steps of the experiment in stages. This includes a visual explanation of how to place the smartphone for data capture using the sensor app. Maeng et al. (2020) emphasized the importance of adding more detailed illustrations in technology-based experimentation guides, which can help students understand the use of devices more clearly and practically. Without supporting illustrations, the instructions in the module can feel abstract and difficult

to follow, especially for students who are using technology in experiments for the first time.

In addition, difficulty in understanding technical terminology is also an obstacle in using this module. Some of the terms used, especially those related to smartphone sensors and data analysis, are still considered difficult for students to understand. Marquardt & Kearsley (2024) state that technology-based learning requires adaptation in understanding digital concepts, and the use of technical terms without adequate explanation can hinder learning effectiveness. This leads to the need to simplify or provide additional explanations related to technical terminology, so that students can more easily understand the experimental instructions provided.

Overall, going forward, improvements to the clarity of the experimental instructions are needed to increase the effectiveness of this module. Strategies such as adding more detailed illustrations, simplifying technical terms, and providing a more complete troubleshooting guide can improve student understanding and increase the success of these technology-based physics experiments.

*Effectiveness of Smart Phone Sensor-based Physics Experiment Module*

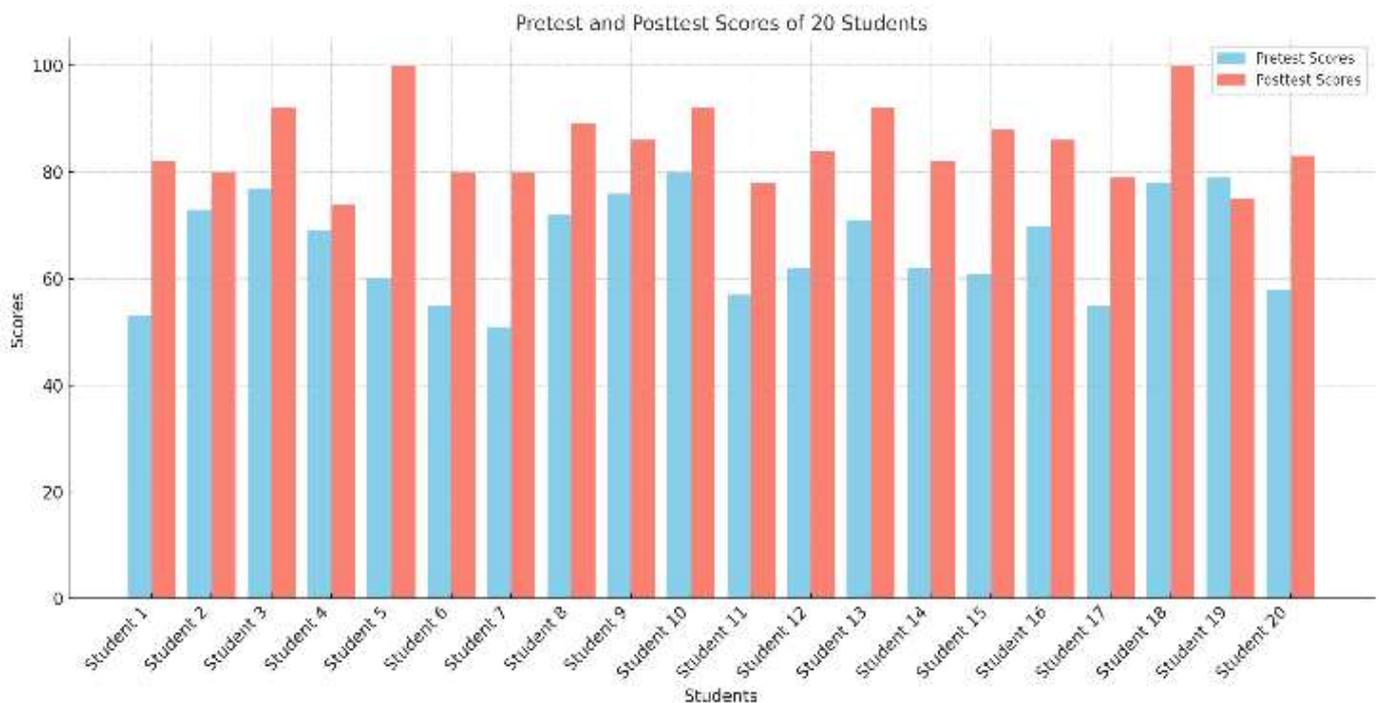
The effectiveness of the smartphone sensor-based physics experiment module was tested through an

operational field trial involving 20 students. These students first used the module to conduct physics experiments, with the aim of evaluating the extent to which the module was able to improve their understanding of physics concepts, as shown in Figure 5.



**Figure 5.** Students conduct simple harmonic motion physics

Testing the effectiveness of the module was done through pretest and posttest given to 20 students after they completed the physics experiment using this module. Comparison of pretest and posttest results showed an increase in students' understanding after using the module, which is visualized in Figure 6. This result is an indicator that the developed module has a positive impact on experiment-based learning, especially in facilitating students to understand the concepts of waves and optics more deeply.



**Figure 6.** Pre-test and post-test score

The results of the module effectiveness analysis shown in the bar chart showed a significant increase in

the posttest score compared to the pretest for the 20 students involved in the study. The average score

increased from 65.95 to 85.1, with an N-gain of 0.55, which is categorized as “medium”. This increase shows that the use of the smartphone sensor-based physics experiment module has helped students understand the concept of waves and optics more deeply. The majority of students experienced a fairly high score increase, with some of them achieving posttest scores above 80, even some reaching the maximum score of 100. This indicates that sensor technology-based experiments integrated in the module are able to provide a more interactive and applicable learning experience, which is in line with the research of Monteiro et al. (2015) who found that sensor-based experiments can improve students' analytical skills by 40% compared to conventional methods.

Compared to previous research, the effectiveness of this module has similarities with several studies that have tested technology-based experiments in physics learning. Wijayanti et al. (2022) who developed a Phyxox-based module for basic physics learning reported an N-gain of 0.58 (medium-high category), slightly higher than this study. The difference may be due to the simpler topic focus in Wijayanti's study, which only covered mechanics, while the module in this study covers more complex concepts of waves and optics, which require deeper understanding related to the use of sensors and analysis of experimental data. In addition, Junita et al. (2024) reported that the use of smartphone-based modules with more limited experimental coverage can achieve higher effectiveness, with a percentage increase in student understanding of 94-95%. These results suggest that simplicity of material and focus on one concept can contribute to higher learning effectiveness, while broader coverage, as in this study, can make the level of difficulty of the experiment increase.

Although the effectiveness of this module is quite good, there are some students who experience an increase in scores with a smaller difference than others. This could be due to difficulties in analyzing data from sensor applications, lack of experience in using experiment-based technology, or limitations in understanding initial concepts before experiments are conducted. A study by Meletiou-Mavrotheris et al. (2007) revealed that technology-based learning requires support in the form of additional practice in data analysis to ensure that students not only collect data, but can also interpret it correctly. This shows that although the module has been effective in improving conceptual understanding, further improvements are still needed, especially in the aspect of assisting students in analyzing experimental results independently.

## Conclusion

This study developed a smartphone sensor-based physics experiment module for the topic of waves and optics in high school, which proved to be valid, practical, and effective. The validation results show that this module has a score of 3.67 (73.4%) for media and 3.56 (71.2%) for material, while the practicality of the module obtained a score of 3.48 (69.6%), indicating that this module is easy to use. Its effectiveness was evidenced through an increase in pretest to posttest from 65.95 to 85.1, with an N-gain of 0.55 (medium category). The main contribution of this research is to develop smartphone sensor-based wave and optical experiments, which are still rarely researched. The module allows flexible experimentation without a conventional laboratory, supporting independent practicum and project-based learning. Teachers can use it for inquiry-based learning, assisting students in analyzing and interpreting sensor data. In the future, it is recommended to develop similar modules for other physics topics, such as electromagnetism or fluid mechanics, and explore their impact on higher order thinking skills (HOTS). This research strengthens the contribution of sensor technology in more innovative, inclusive and flexible physics learning.

## Acknowledgments

The authors express their gratitude to the MGMP Fisika Kabupaten Sorong for their invaluable partnership and support in this research. Their collaboration played a significant role in the successful development and evaluation of this study. The authors also extend their appreciation to DRTPM Kemdikbudristek for funding this research through the Beginner Lecturer Research Grant (PDP) in 2024.

## Author Contributions

Conceptualization, Endra Putra Raharja and Edi Sutomo; methodology, Endra Putra Raharja; validation, Edi Sutomo and Febrian Andi Hidayat; data curation, Asih Kasan; writing—original draft preparation, Endra Putra Raharja; writing—review and editing, Nia Mangkasa; supervision, Edi Sutomo. All authors have read and agreed to the published version of the manuscript.

## Funding

This research was funded by the Direktorat Riset, Teknologi, dan Pengabdian kepada Masyarakat Kemdikbudristek, grant number 0459/E5/PG.02.00/2024 and the APC was funded by the same grant.

## Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

## References

- Abdelaziz, H. A. (2014). Creative Design of Interactive eLearning Activities and Materials (IEAM). *International Journal of Technology Diffusion*, 5(4), 14–34. <https://doi.org/10.4018/ijtd.2014100102>
- Abdulbasit, K., & Mekuria, Y. S. (2021). Status of Learning Facilities for Primary School Physics Curriculum Implementation in Eastern Ethiopia. *International Journal of Educational Research Review*, 6(3), 218–225. <https://doi.org/10.24331/ijere.894943>
- Alfa, J. (2023). Sound Wave Digital Learning Material Integrated Augmented Reality and CTL Model to Promote Students' 21st Century Skills. *Journal of Education Technology*, 7(4), 599–609.
- Arikunto, S., & Cepi Safruddin A.J. (2009). *Evaluasi Program Pendidikan*. Bumi Aksara.
- Ariyansah, D., Hakim, L., & Sulistyowati, R. (2021). Pengembangan e-LKPD Praktikum Fisika Pada Materi Gerak Harmonik Sederhana Berbantuan Aplikasi Phyphox Untuk Meningkatkan Pemahaman Konsep Peserta Didik. *Jurnal Penelitian Pembelajaran Fisika*, 12(2), 173–181. <https://doi.org/10.26877/jp2f.v12i2.9052>
- Azizah, N. A. (2023). Kecanggihan Smartphone Sebagai Media Pembelajaran Di Era Modern. *Borneo Journal of Islamic Education*, 3(1), 65–73. <https://doi.org/10.21093/bjie.v3i1.6333>
- Baene, M. (2023). Teacher's Strategy in Implementing the Independent Learning Curriculum in the Leading Regions, Remote, and Left Behind (3T). *Scaffolding Jurnal Pendidikan Islam Dan Multikulturalisme*, 5(2), 293–307. <https://doi.org/10.37680/scaffolding.v5i2.2916>
- Donna, R., Ekok, A. S., & Febriandi, R. (2021). Pengembangan Multimedia Interaktif Berbasis Powtoon pada Pembelajaran Tematik di Sekolah Dasar. *Jurnal Basicedu*, 5(5), 3799–3813. <https://doi.org/10.31004/basicedu.v5i5.1382>
- Edokpolor, J. E., & Dumbiri, D. N. (2019). Resource Adequacy and Utilization for Teaching and Learning Effectiveness in Vocational Education Programmes in South-South Nigerian Universities. *Journal of Vocational Education Studies*, 2(1), 1. <https://doi.org/10.12928/joves.v2i1.727>
- Etkina, E., Brookes, D. T., & Planinsic, G. (2019). *Investigative Science Learning Environment: When learning physics mirrors doing physics*. Morgan & Claypool Publishers.
- Ewar, H. A., Bahagia, M. E., Jeluna, V., Astro, R. B., & Nasar, A. (2021). Penentuan Konstanta Pegas Menggunakan Aplikasi Phyphox Pada Peristiwa Osilasi Pegas. *Jurnal Kumparan Fisika*, 4(3), 155–162. <https://doi.org/10.33369/jkf.4.3.155-162>
- Fatmala, firda d., Wahyudi, I., Suyanto, E., & Herlina, K. (2019). The Effect of GIL Assisted Phyphox in Physics Learning Towards Creative Thinking. *Jurnal Pembelajaran Fisika*, 8(2), 141–150. <https://doi.org/10.23960/jpf.v8.n2.202002>
- Hofer, S. I., Schumacher, R., Rubin, H., & Stern, E. (2018). Enhancing physics learning with cognitively activating instruction: A quasi-experimental classroom intervention study. *Journal of Educational Psychology*, 110(8), 1175.
- Junita, O., Sanlan, S., & Khusnani, A. (2024). Development of a Physics Experiment Guidebook Using a Smartphone Assisted by the Phyphox Application. *Jurnal Pendidikan Fisika Dan Teknologi*, 10(1), 29–35. <https://doi.org/10.29303/jpft.v10i1.6679>
- Kiraga, F. (2023). A Study of Problem Solving in Physics Learning: A Systematic Review. *Edufisika Jurnal Pendidikan Fisika*, 8(3), 303–315. <https://doi.org/10.59052/edufisika.v8i3.29446>
- Kurniawan, D. A., Kurniawan, D. A., Astalini, A., & Nasih, N. R. (2019). Persepsi Mahasiswa Pada Penuntun Praktikum Fisika Dasar II Berbasis Mobile Learning. *Jurnal Pendidikan Teori Penelitian Dan Pengembangan*, 4(4), 516. <https://doi.org/10.17977/jptpp.v4i4.12345>
- Linn, M. C., & Eylon, B. S. (2011). *Science learning and instruction: Taking advantage of technology to promote knowledge integration*. Routledge.
- Lukitasari, M., & Murtafiah, W. (2021). Pelatihan Peningkatan Kualitas Pembelajaran Dan Reformasi Sekolah Melalui Lesson Study for Learning Community (Lslc) Di SMPN 1 Dolopo Kabupaten Madiun. *Patikala Jurnal Pengabdian Kepada Masyarakat*, 1(2), 65–80. <https://doi.org/10.51574/patikala.v1i2.164>
- Maeng, J. L., Mulvey, B. K., Smetana, L. K., & Bell, R. L. (2013). Preservice teachers' TPACK: Using technology to support inquiry instruction. *Journal of Science Education and Technology*, 22, 838–857.
- Marquardt, M. J., & Kearsley, G. (2024). *Technology-based learning: Maximizing human performance and corporate success*. CRC Press.
- Mayer, R. E. (2002). Multimedia learning. In *Psychology of learning and motivation* (Vol. 41, pp. 85–139). Academic Press.
- Mayer, R. E., & Moreno, R. (2002). Animation as an aid to multimedia learning. *Educational psychology review*, 14, 87–99.
- Moeed, A. (2013). Science Investigation That Best Supports Student Learning: Teachers Understanding of Science Investigation. *The International Journal of Environmental and Science Education*, 8(4), 537–559. <https://doi.org/10.12973/ijese.2013.218a>

- Meletiou-Mavrotheris, M., Lee, C., & Fouladi, R. T. (2007). Introductory statistics, college student attitudes and knowledge—a qualitative analysis of the impact of technology-based instruction. *International Journal of Mathematical Education in Science and Technology*, 38(1), 65-83.
- Monteiro, M., Stari, C., Cabeza, C., & Marti, A. C. (2015). The Atwood machine revisited using smartphones. *The Physics Teacher*, 53(6), 373-374. <https://doi.org/10.1119/1.4928357>
- Musharyadi, F. (2024). Hubungan Intensitas Penggunaan Smartphone Dengan Kecenderungan Nomophobia Pada Remaja. *Menara Medika*, 6(2), 186-195. <https://doi.org/10.31869/mm.v6i2.5189>
- Nurfadilah, N., Ishafit, I., Herawati, R., & Nurulia, E. (2019). Pengembangan Panduan Eksperimen Fisika Menggunakan Smartphone dengan Aplikasi Phyphox Pada Materi Tumbukan. *Jurnal Penelitian Pembelajaran Fisika*, 10(2), 101-107. <https://doi.org/10.26877/jp2f.v10i2.4019>
- Poo, M. C. (2023). Are Virtual Laboratories and Remote Laboratories Enhancing the Quality of Sustainability Education? *Education Sciences*, 13(11), 1110. <https://doi.org/10.3390/educsci13111110>
- Puslitjakov, T. (2008). *Metode Penelitian Pengembangan*. Pusat Penelitian Kebijakan dan Inovasi Pendidikan Badan Penelitian dan Pengembangan Departemen Pendidikan Nasional.
- Rahardjanto, A., & Husamah, H. (2022). Publication Trend of R&D in the Journal of Biological Education in Indonesia (Sinta 2: 2017-2021): A Systematic Literature Review. *Prisma Sains Jurnal Pengkajian Ilmu Dan Pembelajaran Matematika Dan Ipa Ikip Mataran*, 10(1), 21. <https://doi.org/10.33394/j-ps.v10i1.4769>
- Raharja, E. P. (2024). Development of a Physics Experiment Module Based on Smartphone Sensors on Mechanics for High School Students. *Jurnal Riset Dan Kajian Pendidikan Fisika*, 11(1), 1-10. <https://doi.org/10.12928/jrkipf.v11i1.634>
- Raharja, E. P., Irianti, M., Lestari, R. D., Londong, C. M., & Mudumi, S. (2024). Analyzing Physics Experiment using Sensor Smartphone in Traveling Carnival. *Jurnal Penelitian Pendidikan IPA*, 10(3), 1247-1254. <https://doi.org/10.29303/jppipa.v10i3.6792>
- Raharja, E. P., & Ishafit. (2021). Development of circular motion experiment tool using sensor smartphone for high school students. *Journal of Physics: Conference Series*, 1806(1). <https://doi.org/10.1088/1742-6596/1806/1/012048>
- Raharja, E. P., & Kusiana, R. (2020). Pengembangan Modul Praktikum Gerak Melingkar untuk Siswa Kelas X SMA Muhammadiyah 4 Yogyakarta. *JIPFI Jurnal Penelitian Pendidikan Fisika*, 5(2), 151-157. <http://ojs.uho.ac.id/index.php/JIPFI>
- Rahayu, P. (2024). Peningkatan Kompetensi Guru Dalam Pembelajaran Berbasis TIK Melalui in House Traingin (IHT) Di SDN 02 Moga. *Edukatif Jurnal Ilmu Pendidikan*, 6(1), 146-162. <https://doi.org/10.31004/edukatif.v6i1.5757>
- Raiyn, J. (2016). The Role of Visual Learning in Improving Students' High-Order Thinking Skills. *Journal of Education and Practice*, 7(24), 115-121.
- Rudi, A., & Iskandar, A. (2022). Development of teaching methods using infographic media and comic life practice towards students learning interests. *Ceddi Journal of Education*, 1(1), 1-5.
- Sari, M. I. P., Kuswanto, H., & Khafid, M. A. (2022). Analysis of Use of Phyphox Applications for Physics Practicums Using Smartphones on Collision Material. *Jurnal Pendidikan Matematika Dan Ipa*, 13(2), 156. <https://doi.org/10.26418/jpmipa.v13i2.46254>
- Shabiralyani, G., Hasan, K. S., Hamad, N., & Iqbal, N. (2015). Impact of visual aids in enhancing the learning process case research: District Dera Ghazi Khan. *Journal of education and practice*, 6(19), 226-233.
- Shakur, A., & Kraft, J. (2016). Measurement of Coriolis Acceleration With a Smartphone. *The Physics Teacher*, 54(5), 288-290. <https://doi.org/10.1119/1.4947157>
- Tanuwijaya, N. S., & Tambunan, W. (2021). Alternatif Solusi Model Pembelajaran Untuk Mengatasi Resiko Penurunan Capaian Belajar Dalam Pembelajaran Tatap Muka Terbatas Di Masa Pandemi Covid 19. *Jurnal Manajemen Pendidikan*, 10(2), 80-90. <https://doi.org/10.33541/jmp.v10i2.3272>
- Tong, I. W., & Pratama, J. (2023, May). Effectiveness Study and Analysis of Infographics in Promoting Cancel Culture Awareness among Batam City Young Generations. In *CoMBInES-Conference on Management, Business, Innovation, Education and Social Sciences* (Vol. 3, No. 1, pp. 211-224).
- Tuzón, P., & Solbes, J. (2016). Particle Physics in High School: A Diagnose Study. *Plos One*, 11(6), e0156526. <https://doi.org/10.1371/journal.pone.0156526>
- Vogt, P., & Kuhn, J. (2012). Analyzing free fall with a smartphone acceleration sensor. *The Physics Teacher*, 50(3), 182-183. <https://doi.org/10.1119/1.3685123>
- Wahyudi, I., Ashra, V. A., & Suyanto, E. (2022). The Effect of Phyphox Application Assistant Guided Inquiries on Ability Student Creative Thinking.

- Jurnal Pendidikan Matematika Dan Ipa*, 13(1), 1.  
<https://doi.org/10.26418/jpmipa.v13i1.42590>
- Wijayanti, A., Marwoto, P., Wiyanto, W., Ridlo, S., & Parmin, P. (2022). Contextual Science Learning using Smartphone Audio Sensor Application (Phyphox) on Restitution Coefficient Measurement. *Jurnal Penelitian Dan Pembelajaran IPA*, 8(2), 256.  
<https://doi.org/10.30870/jppi.v8i2.13400>
- Yasaroh, S., Kuswanto, H., Ramadhanti, D., Azalia, A., & Hestiana, H. (2021). Utilization of the phyphox application (physical phone experiment) to calculate the moment of inertia of hollow cylinders. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, 10(2), 231-240.  
<https://doi.org/10.24042/jipfalbiruni.v10i2.9237>
- Yulianto, A., Jayanti, I., Rahman, N., & Sajidah, A. H. B. (2023). Gambaran Smartphone Addiction Pada Remaja Di Tangerang Selatan. *Jurnal Psikologi Dan Konseling West Science*, 1(02), 131-137.  
<https://doi.org/10.58812/jpkws.v1i02.238>