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Development of a physics experiment module based on smartphone sensors on mechanics for high school students

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Abstract
Managing physics laboratory equipment often necessitates substantial funding, resulting in infrequent physics practicums, particularly in schools located in remote and economically challenging areas (3T areas). This research endeavors to address this challenge by developing a valid and practical physics experiment module based on smartphone sensors, thereby facilitating easier access to experiments for students. Employing a research and development (R&D) approach, the development process adheres to the Borg & Gall procedural model. Material experts validated the module, yielding an average score of 90.75% in the appropriate category, while media experts rated it 88.75% in the highly suitable category. A practicality test involving 25 students produced an average score of 89.25% in response to the questionnaire. The research results show that this smartphone-based physics experiment module is valid and practical so it can be recommended for high school laboratory practicums, providing a cost-effective and easily accessible solution for improving physics education.

Keywords: sensor smartphone, experiment module, mechanics

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I. Introduction

Physics is one of the fundamental sciences supporting science and technology development [1]. However, physics continues to be considered a challenging subject by most high school students. Learning physics requires practical experiences or direct observations to comprehend the taught concepts [2], [3] In physics classrooms, students often receive theoretical explanations of ideas and need more practical experiences [4]. Consequently, this can lead students to memorize physics formulas and theories without grasping the underlying concepts.

Apart from the lack of practical experiences, in many schools, especially in remote or underprivileged areas ("3T" areas), facilities and physics experimental tools are often limited and inadequate, making it difficult for students to conduct physics experiments independently [5]. Several schools in the 3T areas only have physics experiment equipment such as measuring cups and simple scales. The restricted availability of physics laboratory equipment facilities results in infrequent utilization of experimental methods in learning. This makes physics learning mostly explained conceptually without practical experience in the laboratory.

Establishing well-equipped physics laboratories requires substantial funding for most schools, especially in 3T areas. Specific physics equipment, such as spectrometers, oscilloscopes, and accurate measuring tools, can be expensive. Moreover, managing a physics laboratory also demands high operational costs such as electricity, water, and chemicals. The availability of adequate physics laboratories also depends on the budget allocated by the school or educational institution. Schools or educational institutions sometimes lack the funds to develop a well-equipped physics laboratory.

The advancement of science and technology is increasingly driving the utilization of technological developments in learning [6]. The incorporation of technology in physics education can be exemplified by the development of smartphone sensor-based physics experiment modules [7]. Modules exemplify teaching material development, crafted through steps like needs analysis, design, implementation, assessment, and quality assurance to ensure educational effectiveness [8]. These modules are designed by harnessing smartphone sensors as portable and user-friendly physics experimental tools. Given the widespread use of smartphones among the general population, including students, utilizing smartphone sensors allows more accessible and more affordable access to physics experiments, especially for those lacking access to more expensive experimental equipment [9].

In the development of smartphone sensor-based physics experiment modules, the reliance on costly experimental equipment can be minimized, consequently reducing the costs and time required for experiment preparation and execution. Furthermore, using smartphone technology, experimental data can be processed and presented more efficiently and accurately [10]. Using smartphone sensor-based physics experiment modules can enhance the quality of physics learning, enabling students to engage in more interactive and compelling physics experiments, thereby aiding in better comprehension of physics concepts [11].

A significant portion of physics learning occurs indoors, predominantly in classrooms, to deliver curriculum-based material [12]. While classroom-based physics learning isn't inherently problematic, it becomes challenging when students are asked to comprehend the application of physics concepts in everyday life, such as the application of physics concepts in a playground. This approach could alleviate student boredom during physics learning [13].

Based on the issues above, the researcher is interested in conducting a study on developing smartphone sensor-based physics experiment modules focused on mechanics for high school students. This smartphone sensor-based module was developed using various practicums that are close to students' daily lives, without making expensive experimental equipment. The contribution of this research lies in providing a cost-effective and feasible solution to the constraints faced by schools with limited laboratory resources. By introducing smartphone sensor-based modules, students can gain practical insights into physics concepts, thereby enriching their learning experiences and potentially cultivating a greater interest in the field of science.

Several previous studies have explored the use of smartphone sensors in physics education. One relevant study that can be referenced is the research conducted by Asiyah et al. & Nurfadilah et al. [14], [15]which developed a guide for smartphone sensor-assisted physics experiments. The novelty of this research lies in developing smartphone sensor-based physics experiment modules with a broader range of experiments focusing on mechanics. Additionally, this study aims to overcome the limitations of facilities and physics experimental tools in schools by conducting experiments utilizing the surrounding environment without designing new experimental tools. The advantage of the smartphone sensor-based physics experiment modules in mechanics is that they can assist students in gaining sufficient practical experience in understanding physics concepts without relying on expensive and limited physics laboratory facilities. So, this research aims to create valid and practical physics experiment modules that facilitate students in conducting physics experiments more efficiently.

II. Methods

This research uses research and development or R&D methods. The development model in this research uses a procedural model. Procedural models are descriptive and show the steps that must be followed to produce a product [16]. The development steps in this research were adapted from Borg & Gall, as in Figure 1. Borg & Gall's model involves ten stages, starting with (1) Research and information collecting, where initial information is collected to understand the problems experienced by students and teachers regarding physics experiments. This is followed by (2) Planning, where a detailed module design for module development is formulated. The third stage, (3) Develop preliminary form of product, by carrying out several simple physics experiments using smartphone sensors.

The next stages include (4) Preliminary field testing, where the initial product is tested by material and media experts to identify major problems; (5) Main product revision, including product modifications based on feedback from experts; and (6) Main field test, where the revised product undergoes in-class testing by 25-50 students. This leads to (7) Operational product revisions, refining the product after significant testing. (8)

Operational field tests assess product performance under general use conditions. After that, (9) Final product revisions were performed, finalizing the product based on all feedback and testing. Finally, (10) Dissemination and implementation, the stage where the final product is made available for wider use, ensuring the product reaches its intended audience effectively.

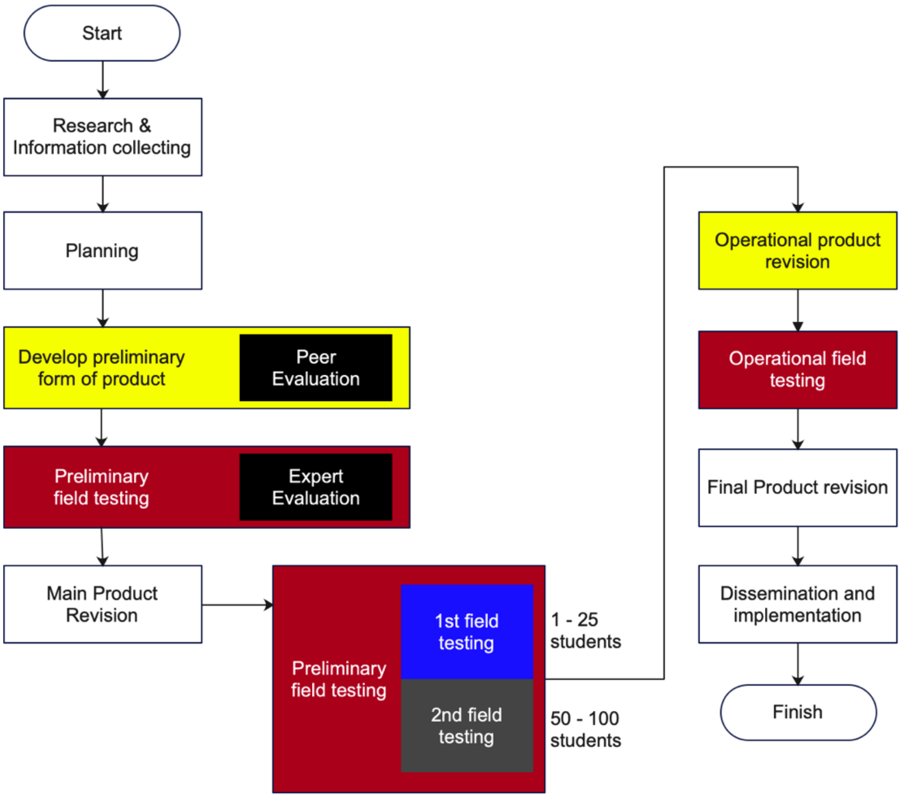

Figure 1. The development steps

Validation sheets that validators have assessed are analyzed to determine the quality and validity of the product. The score for each questionnaire is obtained using the following formula:

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

where P is the percentage, S is the number of scores and N is the amount of data. From the percentage obtained, it is converted into a qualitative sentence. Qualitative criteria can be seenin Table 1.

Table 1. Example of a table format

Interval (P)	Eligibility Level Criteria
80% – 100%	Strongly Agree
66% – 79%	Agree
56% – 65%	Disagree
0 – 55%	Don't agree

This research is considered feasible if the value interval is obtained at 80% - 100% in the "very feasible" category and 66% - 79% in the "feasible" category [17].

III. Results and discussion

Research & Information Collecting

At this stage, the team conducted direct interview observations with high school teachers in Sorong Regency and created a questionnaire regarding student needs analysis. The team reached 120 students in all high schools in Sorong Regency, with further results which can be seen in Table 2.

Table 2. Student Needs Questionnaire Results

No.	Question	Number of students who answered			
		Strongly agree	Agree	Disagree	Dont agree
1	The physics practicum module currently used at school has helped me understand physics concepts well	12	32	60	16
2	I felt I needed to have access to more diverse physics practicum modules to explore physics concepts in more depth	50	43	23	4
3	The physics practicum modules currently available are pretty easy to understand and relevant to the curriculum	9	10	80	21
4	I have a smartphone	109	8	3	0
5	I prefer physics practical modules that include experiments that I can do using simple devices such as everyday tools	86	21	7	3
6	Physics practical modules related to technological applications, such as the use of smartphone sensors, would be exciting for me	90	21	5	4
7	I want a physics practical module that includes experiments that can help me connect physics concepts to the real world	92	18	5	5
8	I want to have a physics practicum module that can be accessed digitally to make it easier to access and learn outside of school	73	32	11	4
9	Physics practicum modules that are adjusted to a level of difficulty that suits my abilities will help me learn more effectively	91	18	10	1
10	I would be more eager to participate in a physics practicum if the module offered challenging and interactive experiments	98	28	3	1

Based on the results of the questionnaire above, it was found that some students may feel satisfied with the existing physics practicum module, but some feel they need more variety and access. Students also have a significant interest in physics practical modules that include the use of technology, such as smartphone sensors. Students prefer practical modules that can help them relate physics concepts to the real world. Students also desire more detailed guidance in the physics practical module. Students enjoy the challenging and interactive experiments in the physics practicum module.

Planning

Based on the analysis of problems and student needs that have been obtained, the media used can be a Physics experiment guide that utilizes smartphone sensors. The resulting media is expected to increase effectiveness and efficiency in the learning process. This media is designed to be as interesting as possible as a guide for experiments in learning. Each student will understand the learning material with the help of instructions from the experimental guide provided.

Apart from developing the content design for the book product, the team also explored physics material that could be included in the guidebook. This activity was carried out at Aimas Square, Kab. Encourage by making use of existing game vehicles. Some of the material obtained includes circular motion and simple harmonic motion, as in Figure 2.

Figure 2. The team explored physical materials for smartphone sensors

Develop preliminary form of product

The results of the development of a draft of a smartphone sensor-based Physics experiment guidebook on mechanics material for high school students are as in Figure 3 & 4, which consists of a cover, table of contents, instructions for using the application, concept map, materials, experimental activities, etc.

Figure 3. The contents of the module (cover, instructions for using the application, & topic)

The module comprises several key components designed to facilitate an engaging and comprehensive learning experience. It begins with a cover that visually introduces the subject and creates an inviting first impression for the learners. Following the cover, there are detailed instructions on how to use the application, which guide the students through the process of setting up and effectively utilizing the smartphone sensors for physics experiments. This ensures that users can navigate the app with ease, maximizing the educational potential of the module. The core of the module is dedicated to the topic at hand, which in this case is mechanics, providing a structured and in-depth exploration of the subject matter. Through these elements, the module aims to deliver a user-friendly and informative resource for high school students embarking on physics experiments.

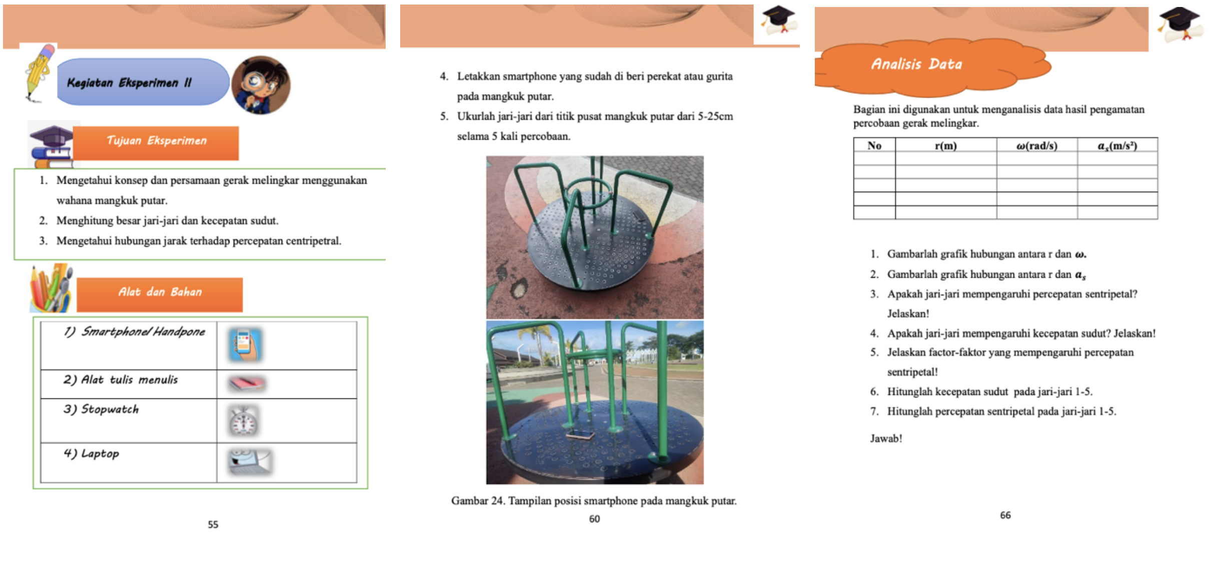

Figure 4. experimental activities

The module features experimental activities encompassing various physics experiments utilizing smartphone sensors, including free fall motion, circular motion, and collisions. Each activity within the module is structured to include specific components such as objectives, tools, and materials required for the experiment. It incorporates data recording sheets to systematically document the experimental results, analysis sheets to interpret the collected data, a section for posing relevant questions, and a conclusion segment to summarize findings. This comprehensive approach ensures that learners engage in a structured and informative exploration of physics concepts, enhancing their understanding through hands-on experimentation with smartphone sensors.

Preliminary field testing

At this stage, validation results are obtained from media experts, and product revision material is obtainedfrom experts. Media experts include aspects of media visual, cover design, and media content design. The validation results by five validators are as table 3.

Table 3. Media Expert Validation Results

Assessment Indicator	Average Assessment Score for Each Category	Percentage score (%)	
Media Visual	3.43	87.75	Very Decent
Cover Design	3.56	89.00	Very Decent
Media Content Design	3.66	91.50	Very Decent
Overall Average Rating Score	3.55	88.75	Very Decent

Description: Suitable for use

The Media Expert Validation Results for the physics experiment module based on smartphone sensors focusing on mechanics for high school received commendable evaluations across key aspects. In the category of "Media Visual," the module scored 3.43, equivalent to 85.75%, indicating a very decent assessment. The "Cover Design" earned a score of 3.56, translating to 89%, also denoting a very decent evaluation. Additionally, the "Media Content Design" achieved a notable score of 3.66, reaching 91.5%, maintaining its very decent rating. These results collectively affirm the high-quality design and appropriateness of the visual elements, cover design, and content layout within the module, as recognized by media experts, highlighting its effectiveness for high school students studying mechanics through smartphone sensor-based experiments.

The results of validation by material experts include material aspects, language aspects, and presentation and appearance aspects. The results of module validation by five validators are shownin Table 4.

Table 4. Material Expert Validation Results

Assessment Indicator	Average Assessment Score for Each Category	Percentage score (%)	
Material	3.50	87.50	Very Decent
Languages	3.80	95.00	Very Decent
Presentation and Appearance	3.60	90.00	Very Decent
Overall Average Rating Score	3.63	90.75	Very Decent

Description: Suitable for use

The Material Expert Validation Results for the physics experiment module based on smartphone sensors, focusing on mechanics for high school, showcase strong endorsements across key dimensions. Under the "Material" category, the module received a score of 3.50, equivalent to 87.5%, signifying a very decent evaluation by material experts. Similarly, in the "Languages" category, the module excelled with a score of 3.80, reaching 95%, maintaining a very decent rating. The third aspect, "Presentation and Appearance," secured a score of 3.60, or 90%, also falling within the very decent category. These outcomes collectively highlight the module's high-quality content, language usage, and overall presentation, reinforcing its suitability for high school students studying mechanics through smartphone sensor-based experiments, as acknowledged by material experts.

Main product revision

The development of the experimental guidebook received several improvements that had to be made based on the results of assessments by material and language experts, media experts, and student responses to the experimental guidebook. The results of the improvements made by the validator are shown in Table 5.

Table 5. Revision of validators and follow-up

Suggestions	Follow-up
Media is made more practical from size 4 4 3 3 to size 2 2 2 2, and the color of the cover, images, and media must be changed	Media is made to the requested size
Add physics material about other mechanics	Add material about free-fall motion, rectilinear motion, and collisions
Material experts recommend consistently simplifying language and writing to facilitate student understanding	Language and writing are simplified
Cover has been made simpler and more elegant	The cover has been redesigned with a combination of colors and letters with an appropriate layout

Following the feedback from validators, the module underwent several revisions and improvements to enhance its educational value and appeal. The media's dimensions were adjusted from the initial size of 4x4x3x3 to a more practical 2x2x2x2, alongside modifications to the cover's color, images, and overall media presentation to meet the validators' recommendations. Additionally, the physics content was expanded to include topics on free-fall motion, rectilinear motion, and collisions, enriching the module's material breadth. To make the module more accessible to students, material experts' advice on simplifying the language and writing style was implemented, ensuring clearer understanding. The cover design was also revamped to a simpler yet more elegant aesthetic by adjusting the color scheme and layout of the letters. Furthermore, to aid in the comprehension of data analysis, examples were added to the book's final page, providing students with practical insights into interpreting experimental results. These revisions collectively contribute to a more effective and user-friendly educational tool for high school students engaging in physics experiments through smartphone sensors.

Main field testing

At this stage, a user questionnaire and practicality test of the module were carried out by 25 students. The results of the questionnaire are as in the following Table 6.

Table 6. User questionnaire Results

Assessment Indicator	Average Assessment Score for Each Category	Percentage score (%)	
Material	3.46	86.50	Very Decent
Languages	3.75	93.75	Very Decent
Presentation and Appearance	3.55	88.75	Very Decent
Clarity of Experimental Instructions	3.45	86.25	Very Decent
Practicality and Complexity of Experiments	4.65	91.25	Very Decent
Overall Average Rating Score	3.57	89.25	Very Decent

Based on the results above, students feel that the experimental module created is efficient in terms of material, Language, Presentation and Appearance, Clarity of Experiment Instructions, Practicality, and Complexity of the Experiment. The average score obtained was 89.25% in the very decent category.

In the course of its development, the physics experiment module based on smartphone sensors for high school mechanics underwent the initial six stages of the Borg and Gall model, achieving very decent scores across these phases. This level of validation and feedback signifies that the module effectively meets the required standards and objectives set forth at these stages, demonstrating its quality and the adequacy of its content, design, and educational approach. As a result of these satisfactory evaluations, the decision was made not to proceed to the subsequent stages of the Borg and Gall development process. This decision reflects confidence in the module's current state, suggesting that it possesses the necessary attributes to serve its educational purpose without further modifications or testing in the immediate phases, thus streamlining the development process while ensuring the module's readiness for educational application.

Discussion

This research has gone through 6 stages of development to produce a valid and practical experimental module for students. The validation results from 5 material experts obtained an average score of 90.75% in the appropriate category. Meanwhile, the validation results from 5 media experts obtained an average score of 88.75% in the very appropriate category. In the practicality test, a response questionnaire was carried out on 25 students with an average score of 89.25%. With these results, the physics experiment module based on smartphone sensors on mechanics for high school students is declared suitable.

These results are not much different from the results of module development that have been developed by several researchers, such as in the development of Free Fall Movement practicum tools using the Phyphox application, which uses Research and Development (R&D) research methods with 4D models (define, design, develop and disseminate) [18]. Other research was also carried out with the development of Physics Practical e-LKPD on Simple Harmonic Motion Material with the Help of the Phyphox Application. This research uses development (Research and Development) with the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) development model [19]. Development of other modules was carried out in the form of LKPD on material on sound waves and the Doppler effect based on Guided Inquiry with valid results using the ADDIE development model [20], [21], [22]. The difference between these two studies is that the method used by researchers is Research and Development (R&D) with the Borg & Gall model. Apart from that, the materials and products produced are also different. Namely researchers focus on mechanics material for high school students with physics experimental module products.

This research corroborates prior studies that utilized smartphone sensors as a medium for gathering data in physics experiments. Smartphone sensors, through specific applications, have been effectively employed in experiments such as the Biot–Savart law, demonstrating how the magnetic field decreases in proportion to $1/r^2$ [23]. Students particularly found using their smartphones for conducting experiments, like a physical pendulum experiment using Lego and Phyphox, to be enjoyable [24]. Phyphox has been used to measure the magnetic field of a low-frequency LC-circuit, yielding very satisfactory results due to the high resolution of the graph and the measurements' alignment with theoretical values. Furthermore, this setup is notable for its accessibility, as it can be accomplished using low-cost components [25].

IV. Conclusions

A physics experiment module based on smartphone sensors has been developed on mechanics for high school students. The validation results from 5 material experts obtained an average score of 90.75% in the appropriate category. Meanwhile, the validation results from 5 media experts obtained an average score of 88.75% in the very appropriate category. In the practicality test, a response questionnaire was carried out on 25 students with an average score of 89.25%. With these results, the physics experiment module based on smartphone sensors on mechanics for high school students is declared suitable.

The recommendation of this research is that integrating smartphone sensor-based modules into high school physics practicums presents a cost-effective and accessible method to enhance physics education. This approach utilizes the widespread availability of smartphones to enable practical, hands-on experiments, making advanced scientific learning accessible to a broader range of students.

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