



Development of IoT-Based Physics Practicum Module Using Physics Digital Props for Particle Dynamics Learning

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Abstract

This study aimed to develop a Physics practicum module based on Physics Digital Props (PDP) for particle dynamics learning and to examine its feasibility, practicality, and effectiveness. The research employed a Research and Development approach using the 4D model, consisting of define, design, develop, and disseminate stages. The participants were tenth-grade senior high school students involved in limited and field trials. The research instruments included expert validation sheets, student response questionnaires, and conceptual understanding tests. Data were analyzed using descriptive quantitative techniques. The results showed that the module achieved a feasibility score of 88.6% from material experts and 90.2% from media experts, both categorized as very feasible. Student responses indicated a practicality level of 89.4%, classified as very good. Furthermore, students' conceptual understanding improved significantly, as indicated by an N-gain score of 0.72 in the high category. These findings demonstrate that the PDP-based practicum module is feasible, practical, and effective for physics learning. The novelty of this study lies in the integration of Physics Digital Props as an interactive digital practicum medium that supports experimental-based learning. The developed module is expected to serve as an innovative alternative for teaching particle dynamics and to encourage the development of technology-integrated instructional materials in physics education.

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INTRODUCTION

Physics education plays a crucial role in preparing students to face the challenges of the era of technology and innovation [1]. Physics learning not only strengthens scientific foundations but also develops analytical and problem-solving skills. However, conventional teaching methods are often insufficient to stimulate students' interest and promote deep conceptual understanding [2],[3].

Practical learning is considered an effective instructional approach to enhance students' cognitive and practical skills, as it requires active engagement in problem-solving activities. In physics education, the focus is on ensuring students' active participation as learners through the use of relevant natural phenomena [4], which can help them gain a deeper and more comprehensive understanding of physical concepts. Therefore, the implementation of modeling activities or practicum sessions is regarded as essential in physics learning.

Although physics practicum has long been recognized as an effective method for teaching complex concepts, many institutions still rely on conventional practicum modules that do not utilize recent technological advancements [5],[6]. These limitations include inadequate laboratory equipment, unsafe or uncomfortable laboratory conditions, limited interactivity, lack of personalized learning, minimal use of real-time data to support experiments, and varying practicum experiences among

students depending on equipment availability, instructional quality, and teacher supervision. Consequently, these factors may lead to inconsistencies in students' understanding and learning experiences of physics concepts.

To improve the quality of physics education, there is an urgent need to integrate innovative technologies such as the Internet of Things (IoT). The application of IoT in practicum-based learning can provide students with opportunities to explore physics concepts through real-time simulations, instant data analysis, and deeper interaction with learning materials [18].

Previous studies have shown that the use of technology in learning processes can significantly increase student engagement and understanding [7],[8],[9]. According to the Programme for International Student Assessment (PISA), students who utilize technology-based learning tools tend to achieve better academic performance than those who rely solely on traditional learning methods [10],[11]. Furthermore, feedback from teachers and students using conventional learning modules indicates a strong need for learning materials that are more technology-oriented [12],[13].

Previous research on the development of physics practicum modules in particle dynamics has demonstrated positive outcomes. Mardiana and Bungkang developed a physics learning module based on particle dynamics contexts to improve students' learning achievement [14],[19],[20] while [15] developed a module using the Contextual Teaching and Learning (CTL) approach for particle dynamics topics. However, these studies have not incorporated IoT-based practicum module development, known as Physics Digital Props (PDP). The PDP product development research has been tested, and the results indicate that the developed physics practicum module has high validity and is highly suitable for helping students understand particle dynamics concepts.

The development of an IoT-based physics practicum module is expected to transform the way students learn physics, making learning more interactive, engaging, and effective [21]. This module is designed to enhance student engagement, deepen conceptual understanding, and provide more personalized and responsive learning opportunities.

Considering the urgency of innovation in physics education, the development of practicum modules based on the Internet of Things (IoT) is highly important and aligns with the national education mission to improve intellectual capacity and produce globally competitive human resources. Therefore, it is essential to continue the development of the PDP (Physics Digital Props) practicum module that has been previously initiated. The objective is to ensure that practicum activities can be conducted in accordance with digital practicum guidelines in teaching particle dynamics.

METHOD

This study employed a Research and Development (R&D) method using the 4D model, consisting of Define, Design, Develop, and Disseminate stages, to develop a physics practicum module based on Physics Digital Props (PDP) for particle dynamics learning. The Define stage involved curriculum analysis, student characteristics analysis, and identification of learning problems in particle dynamics practicum. The Design stage focused on designing the structure of the PDP-based practicum module, including learning objectives, practicum procedures, worksheets, and IoT integration. The Develop stage included product development, expert validation, revision, limited trials, and field trials. The Disseminate stage was conducted in a limited scope by implementing the module in physics learning and sharing it with physics teachers. The participants were tenth-grade senior high school students selected using purposive sampling, based on curriculum suitability for particle dynamics material.

The research instruments consisted of Expert validation sheets for material and media aspects, Student response questionnaires to measure practicality, Conceptual understanding tests to measure effectiveness. Data were collected through expert validation, student questionnaires, and pre-test and post-test results. The data were analyzed using descriptive quantitative techniques with a feasibility percentage formula. The feasibility criteria were determined as Table 1, Learning effectiveness was measured using the N-gain formula.

Table 1. Feasibility Criteria

Percentage	Category
81–100%	very feasible
61–80%	feasible
41–60%	fair
≤40%	not feasible

RESULTS AND DISCUSSION

1. Define

Identifying students' characteristics is a crucial step in designing effective practicum modules that align with learners' needs [16]. Each student possesses distinct characteristics, including academic ability, cognitive development, motivation, and personal skills related to the subject matter, the media used, the format, and the language of instruction. Understanding these characteristics enables educators to design modules that are not only relevant but also accessible and easily comprehensible for students. Practicum modules developed without considering students' characteristics risk being less effective, as they may not match students' levels of understanding or their ability to master the material [17].

Therefore, identifying students' characteristics serves as a fundamental basis in the development of practicum modules so that they can be tailored to individual learners' needs, ultimately enhancing their learning outcomes. Identifying the additional skills required and analysing the core tasks that must be mastered by students are essential steps [23],[26],[27]. These core tasks include all the necessary steps or stages to achieve specific competencies, ranging from the most basic to the more complex levels.

Organizing the key concepts of particle dynamics in a hierarchical structure and distinguishing essential concepts from those that are less relevant is an effective strategy for focusing students' learning on the core elements that support a comprehensive understanding of motion and force [24],[28],[29]. This hierarchy establishes a logical foundation that enables students to develop the analytical skills required to understand particle motion in various physical contexts.

2. Design

The content and structure of the practicum module are developed comprehensively to ensure that each section follows a logical sequence, has clear objectives, and provides appropriate learning materials [30],[31],[33]. The design process includes the following steps:

- (a) Learning Materials: Relevant theoretical content related to the physics topic being practiced is presented concisely and clearly. For example, if the module discusses the concept of force, it includes an introduction to force, Newton's laws, and applicable examples aligned with the experiment.
- (b) Practicum Instructions: Detailed and student-friendly step-by-step instructions are prepared. These instructions cover the use of equipment, the sequence of experimental procedures, and necessary safety guidelines. Clear guidance on how to read data and record results is also provided.
- (c) Learning Activities: Interactive learning activities are designed, such as group discussions, collaborative observations, or simulations. These activities aim to encourage critical and collaborative thinking and to promote active student engagement in the learning process.

3. Development

The experts involved typically include specialists in the relevant physics content, experienced physics educators, and media or educational technology experts who understand the principles of interactive module design. Media or instructional design experts evaluate the visual aspects and layout of the module, including text arrangement, the use of images and diagrams, and the clarity of visual instructions [34],[35]. They assess whether the module is visually appealing, user-friendly, and whether its design effectively supports learning. In addition, they identify areas where the design or interface can be improved, particularly for digital modules that rely on interactive features.

The development of the IoT-based particle dynamics practicum module can be seen in the figure below.



Figure 1. IoT-based particle dynamics practicum module

4. Disseminate

This stage is a critical phase in module development, aimed at evaluating the effectiveness of the module after revisions have been implemented. The purpose is to ensure that the final product meets learners' needs and achieves the intended learning objectives. The module trial results are analysed based on three aspects: validity, effectiveness, and practicality. These aspects are measured by distributing response questionnaires to teachers and students. The summarized responses from teachers and students toward the IoT-based physics practicum module are presented in the following figure,

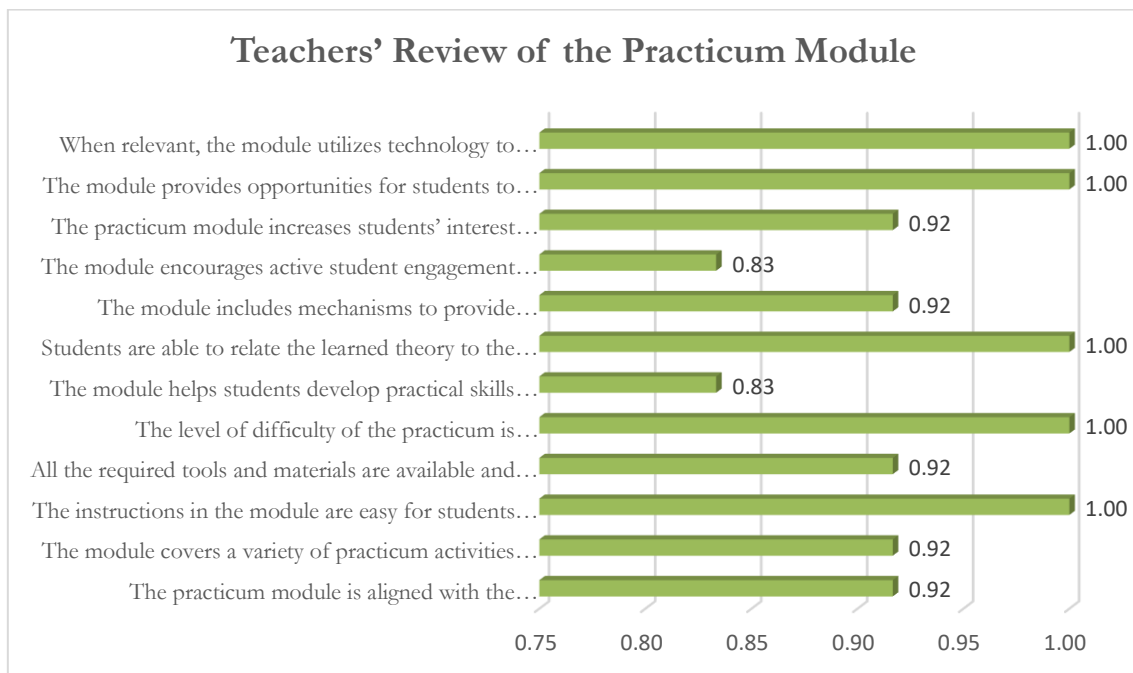


Figure 2. Teachers' Responses

The figure above presents information on teachers' responses to the evaluated aspects of the module trial. During an interview, Muhammad Jayadi, M.Pd. (Physics Teacher) stated: "The most outstanding aspect of the developed module is how it provides clear guidance on using the PDP

practicum equipment integrated with IoT. On the one hand, students are guided to construct their own understanding, and on the other hand, their technological literacy is also fulfilled.”

The results of students’ responses to the IoT-based physics practicum module are presented in the following graph.

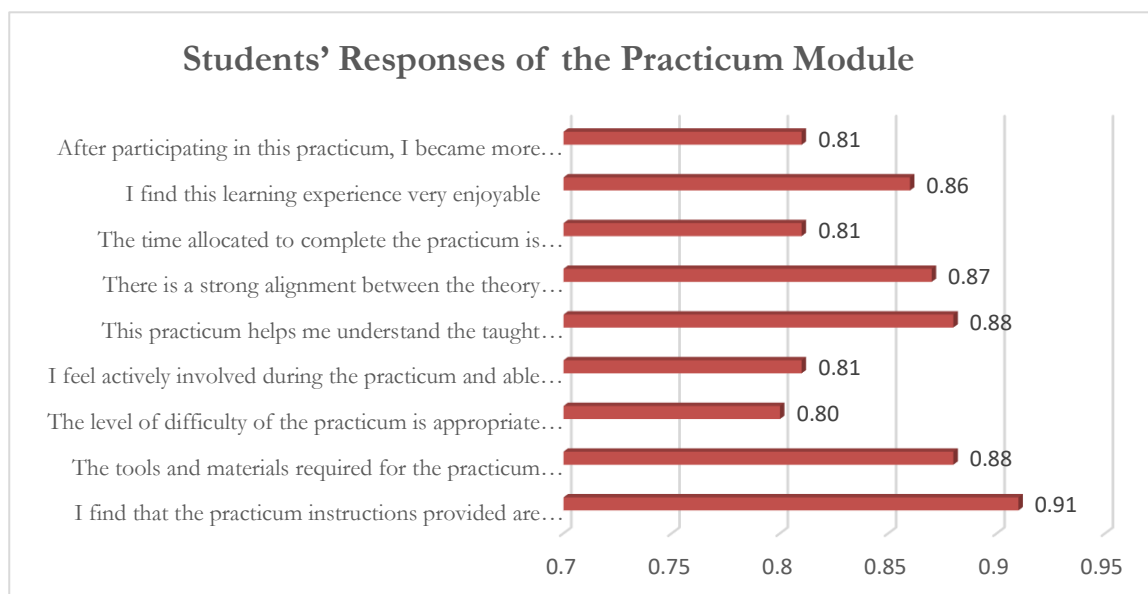


Figure 3. Students’ Responses to the Module

Based on the graph above, the average student response to the practicum module is 0.85, which falls into the very valid category. The practicum instructions are considered very clear and meet the criteria of very high validity across several previously mentioned aspects. This result is also supported by an interview with one of the students, who stated, “The module used in this trial is very clear and helps me understand Newton’s second law more quickly.” In line with this finding, practicum modules can assist students in preparing themselves before laboratory activities by encouraging them to read and understand the material in advance. Moreover, practicum modules can train students’ scientific process skills by providing opportunities to conduct observations, experiments, data analysis, and draw conclusions [22].

The IoT-based physics module on particle dynamics, specifically the sub-concept of Newton’s Second Law, is highly feasible for use in the learning process. Based on the results, teachers’ responses reached 94%, categorized as very practical, while students’ responses reached 85%, categorized as practical, for learning Newton’s Second Law.

These findings are supported by previous related studies [25],[32],[36],[37],[38],[39],[40], which consistently report that IoT-based physics practicum modules are appropriate and effective for use as physics practicum modules on Newton’s Second Law material.

CONCLUSION

The design and development of the IoT-based physics practicum module employed the 4D development model. The stages of this research and development process consisted of Define, Design, Develop, and Disseminate.

The Define stage included the analysis of students’ characteristics, the analysis of core tasks that students must master, and concept analysis. The Design stage involved organizing the content and structure of the module, designing the layout and visuals, and developing evaluation instruments. The Development stage covered expert validation of the module to ensure its quality and relevance, as well as developmental trials. Finally, the Disseminate stage consisted of validation testing to ensure that the final product met learners’ needs and achieved the intended learning objectives, as well as packaging.

The results of media expert validation reached a score of 0.94, categorized as very valid, indicating that the IoT-based physics practicum module on particle dynamics, specifically Newton’s Second Law, is highly feasible for use in the learning process. The module was also proven to be

effective in learning activities, based on teachers' questionnaire responses with a score of 0.94 in the very valid category and students' questionnaire responses with a score of 0.85, also in the very valid category.

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