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DEVELOPMENT OF A DIGITAL SIMULATION-BASED INTERACTIVE MODULE FOR JUNIOR HIGH SCHOOL STUDENTS ON MECHANICS IN THE NATIONAL SCIENCE OLYMPIAD (OSN)

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Abstract

This study introduces a breakthrough by providing the first interactive digital simulation-based module specifically designed for OSN physics training at the junior high school level, integrating multiple simulation platforms into a unified and innovative learning resource, which has not been found in previous OSN modules. The module was developed using the Research and Development (R&D) method, following the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation). It was designed as a web-based resource using Canva and integrated with simulations from GeoGebra and PhET to present physics concepts dynamically and interactively. Validation by three experts from the Institut Teknologi Bandung resulted in an average score of 3.0 for content validity and 3.2 for media validity (on a scale of 4.0), both categorized as very valid. The module was then tested on ten junior high school students from Serang Regency who were prospective OSN participants. The training showed moderate effectiveness, with an average N-gain score of 0.38. Feedback from the participants and a supervising teacher yielded practicality scores of 3.5 and 3.8 (on a scale of 4.0), respectively, indicating the module is highly practical. Based on these results, the module is considered effective, valid, and highly practical, making it suitable as a supporting tool for OSN science training at the junior high school level.

Keywords: training module, OSN, interactive simulation

INTRODUCTION

Physics competitions, such as the International Physics Olympiad (IPhO) and the International Junior Science Olympiad (IJSO), play a significant role in inspiring students to develop a deeper interest in science from an early age [1, 2]. These competitions let participants compare their abilities with others, driven by the desire to learn more and succeed [1, 3]. In Indonesia, the National Science Olympiad (OSN) serves as a prestigious competition that fosters creativity, critical thinking, and scientific excellence among junior high school students [4]. Participation in OSN enhances students' chances of university admission and scholarship opportunities, making it an important milestone for students [5, 6].

To effectively prepare for the OSN, it is essential to use learning resources that cater to students' needs and interests [7]. Thorough preparation can instill confidence in OSN participants, enabling them to perform their best during the competition. However, preparing for such competition requires resources and intensive training [8, 9, 10, 11, 12, 13, 14, 15].

Interview with five teachers from different high schools in Serang revealed that traditional textbooks and classroom instruction often fell short in addressing the depth and complexity of OSN content. One teacher emphasized that physics, particularly mechanics, was one of the most challenging yet essential domains in OSN preparation. They also highlighted a lack of adequate materials to support their students' learning.

Moreover, many OSN physics topics surpass the junior high school curriculum, making it difficult for students to grasp advanced concepts without scaffolding tools [4, 16]. The gap between curriculum content and competition requirements highlights the need for innovative instructional strategies. Recent educational trends advocate for the use of Interactive Engagement (IE) approaches, where learners are actively involved in manipulating variables, conducting simulations, and making conceptual connections [17].

Previous studies on digital modules have not focused on OSN preparation at the junior high level. Most existing modules emphasize skills such as problem-solving, with limited use of interactive simulation and no systematic design for OSN training [18]. Digital tools such as GeoGebra and PhET have become increasingly popular for science learning, for their capacity to increase motivation, deepen understanding, and facilitate visualization of abstract physics concepts [19, 20, 21, 22, 23, 24, 25]. While both platforms offer valuable educational resources, they differ in their approach. GeoGebra provides customizable simulations that cater to specific material, whereas PhET offers a wide range of free simulations that can help visualize general concepts. By combining the strengths of both tools, this study developed an interactive digital module based on simulations using GeoGebra and PhET, focusing on mechanics topics relevant to junior high school OSN physics.

The primary objective of this study was to evaluate the validity, practicality, and effectiveness of the developed module through expert validation and limited classroom implementation. To achieve this goal, a mixed-methods approach was employed, combining qualitative and quantitative procedures for data collection and analysis.

Our paper is structured as follows. Section 2 provides an overview of the research design, including the sampling method, participants, data collection techniques, and analysis procedures used in this study. Section 3 describes the development process in detail, covering the tools and methods used to create the module, its key features, implementation activities, and the results of its effectiveness. Finally, Section 4 concludes the study and discusses its implications for science education, emphasizing the benefits and limitations of using interactive digital modules.

RESEARCH METHOD

This research employed a Research and Development (R&D) approach, using the ADDIE model as its framework. The ADDIE model consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. The study was conducted at SMPN 1 Cikande, Serang Regency, Indonesia. Specifically, the research design involved a mixed-methods approach, combining both qualitative and quantitative data collection and analysis procedures to evaluate the effectiveness of the developed module.

Participants

The participants in this study consisted of five science teachers who were involved in an initial needs analysis, three expert validators from Institut Teknologi Bandung, and ten students (grades 7 and 8) who were selected using purposive sampling based on science teachers' recommendations, with criteria including good academic performance, scientific potential, and readiness as prospective OSN participants.

Research Design

This study employed a one-group pretest-posttest design, which is suitable for evaluating the impact of an intervention when a control group is not feasible due to limited sample size. This design allowed authors to directly observe the effects of the treatment without needing to compare it with a control group.

Instruments and Data Collection

Data collection was conducted using multiple instruments, including:

- Expert validation sheets: These were used to assess the validity and effectiveness of the developed module from the perspective of content experts.
- Students' and teachers' practical questionnaires: These were administered to gather feedback on the usability and effectiveness of the module during the four-week training session.
- Pre-test and post-test scores: Fifteen multiple-choice questions covering core OSN physics topics.

Data Analysis

Data collection was conducted using multiple instruments, including: Quantitative data were analyzed using average Likert scores to assess validity and practicality (Table 1), and the average score on each aspect (validation of material experts, media, and teacher and student responses) using equation (1),

$$X = \frac{\sum X}{n} \quad (1)$$

where $\bar{X}$ denotes the average score, $\sum X$ is the total score, and n is the number of statements. After obtaining the average score, convert it into qualitative values in the form of intervals based on the average score guidelines in Table 2.

The following notations are used, $\bar{X}$ denotes the average of the obtained scores, $\underline{x}$ is the ideal average score which calculated using the formula [26]:

$$\underline{x} = \frac{1}{2}(\max score + \min score) \quad (2)$$

TABLE 1. Likert scales for response questionnaires [26].

Responses	Scores	Interval
Very Good	4.0	$\bar{X} \geq 3.0$
Good	3.0	$3.0 > \bar{X} \geq 2.5$
Good Enough	2.0	$2.5 > \bar{X} \geq 2.0$
Not Good	1.0	$\bar{X} \leq 2.0$

TABLE 2 . Score average guidelines [26]

Scores Intervals	Interval
$\bar{X} \geq (\underline{x} + 1 \times SBi)$	Very Good
$(\underline{x} + 1 \times SBi) > \bar{X} \geq \underline{x}$	Good
$\underline{x} > \bar{X} \geq (1 \times SBi)$	Good Enough
$\bar{X} < (\underline{x} - 1 \times SBi)$	Not Good

and SBi is the standard deviation of the ideal score with coefficient 1, and it is calculated using the formula [26]:

$$SBi = \frac{1}{2}(\max score + \min score) \tag{3}$$

To assess the effectiveness of the module quantitatively, we employed the N-gain score method. This method calculates a normalized gain score by comparing the pre-test and post-test scores. The N-gain score equation is used to determine the average increase in student knowledge from pre-test to post-test. The N-gain score is calculated using the following formula [17]:

$$g = \frac{S_{post} - S_{pre}}{S_{\max} - S_{pre}} \tag{4}$$

where S_{post} is the average post-test score, S_{pre} is the average pre-test score, and $S_{\max}$ is the maximum score. This method allows authors to quantify the effectiveness of the module by determining the average gain in student knowledge after participating in the training session. The effectiveness was classified as high $(g > 0.70)$; moderate $(0.3 \leq g \leq 0.7)$; and low $(g < 0.30)$ [17].

RESULTS AND DISCUSSION

This section presents the findings of the research, which were obtained through the analysis, design, development, implementation, and evaluation stages of the ADDIE model.

Analysis

The analysis stage involved conducting interviews with five science teachers from different schools in Serang Regency to gather information on their teaching practices. The interview questions focused on the following areas, teaching materials commonly used in the classroom, the teaching methods used by the teachers, integration of technology in learning physics concepts, complex concepts for students to understand, and challenges faced by the teacher when teaching physics concepts. A Google Form online questionnaire was used to collect the observation sheets from the interviewees.

In addition, an analysis of the junior high school OSN curriculum was conducted to map key physics concepts, supported by literature studies and previous Olympiad questions from books and online materials to ensure alignment with recent developments in interactive simulation-based modules.

Design

The design of this interactive digital module was developed using the web-based platform Canva, which offered attractive layouts, illustrations, and rich design features. To accommodate

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mathematical equations, the initial content input was done in Microsoft Word, allowing for more flexibility in editing before transferring the content to Canva.

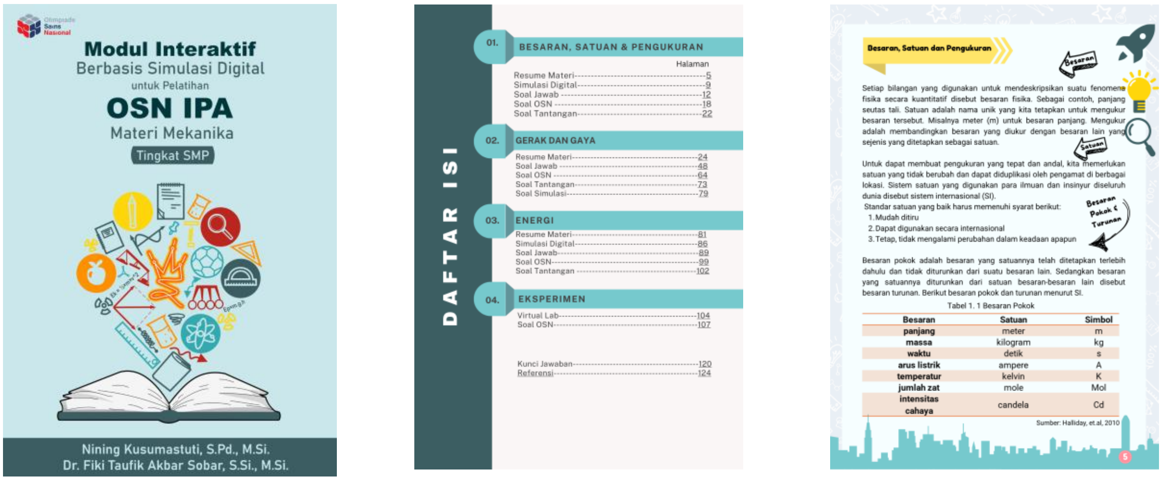
The module design included a range of components such as concept summaries and illustrations, practice problems, OSN past questions, and challenge problems. In addition, it featured eight embedded simulations from GeoGebra and PhET, digital quizzes with immediate feedback, QR codes for interactive access, and scientific boxes containing insights from indexed journal sources, which provided students with a deeper understanding of the scientific concepts being taught. The GeoGebra simulations were embedded directly within the module, allowing users to access and interact with them without switching to an external website.

Development

During the development stage, the module was created based on the syllabus. The design of the cover in Figure 1a is visually attractive, featuring bright and contrasting colours, cute illustrations and graphics, attractive typography, and clear layout. Learners could access the specific topic by pressing the number that indicated the topic page, utilizing the hyperlink feature as a navigator.

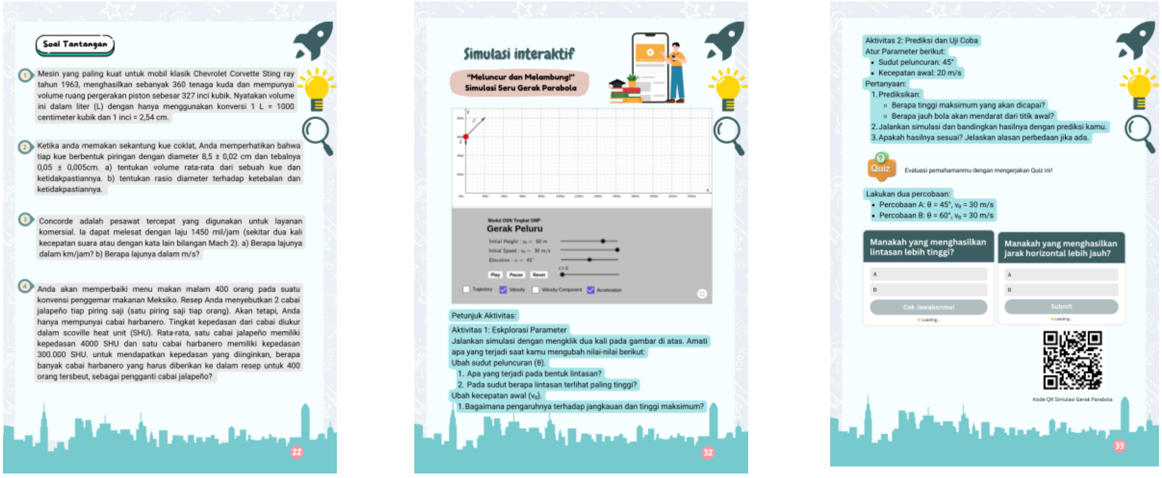
The module consisted of four chapters: magnitude, units, and measurement; motion and force; energy; and experiment (see Figure 1b). Each chapter included resume-style content focusing on key concepts, comprising concept summaries, equations, and supporting images (see Figure 1c). These were sourced from credible literature to ensure accuracy, to avoid misconceptions, and were adapted to the physiological and psychological levels of junior high school students.

Practice questions were prioritized in this module, as it was designed for competition preparation. There are four types of practice questions: answer questions that trained students to think analytically and critically; OSN questions from previous years that familiarized students with the pattern and format of questions they might face in the competition; challenge problems (Figure 2a) that required effective problem-solving strategies and techniques; and interactive simulation questions that allowed learners to engage with the content in a dynamic way.



(a) (b) (c)

FIGURE 1. Modules consisting of (a) cover, (b) table of contents, (c) resume



(a) (b) (c)

FIGURE 2. (a) challenge problem, (b,c) simulation features

To avoid boredom and solidify learners' understanding of OSN materials, interactive digital simulations were able increase learning motivation. Both the simulation and the evaluation questions (Figure 2b) embedded in the module allowed learners to engage with the content interactively, while also provided immediate feedback on their answers. The teacher was able to track students' responses from the quiz recap, making it easy to monitor progress.

The module features ten digital simulations that can be accessed directly through the instructions on each page or by scanning the QR code provided (Figure 2c). One of these simulations was designed to train students' skills in reading precision measuring instruments and reflecting measurement results using digital simulations, as shown in Figure 2c. This simulation was not limited to the first chapter on quantities, units, and measurements, but was also applied to subsequent chapters.

The developed module was validated by two lecturers who were material experts and one lecturer who was a media expert. The validation results showed high levels of content validity (average score of 3.0) and media validity (average score of 3.2), both of which are considered very good categories (Table 3). Based on the feedback, minor revisions were made to improve language clarity and balance between visual and text elements in the layout.

The assessment showed that the module met the criteria of material feasibility, being relevant and aligned with the needs of junior high school students who are prospective OSN participants. Additionally, as a learning medium, the module was shown to be attractive, easy to use, and useful for OSN preparation.

Implementation

Before evaluating the module's effectiveness, the authors conducted a four-week OSN training program to provide an initial briefing to students related to OSN materials as well as introduce them to digital simulation-based modules that had been developed. During the training, students demonstrated high enthusiasm for the interactive physics learning approach. For example, when students scan the QR code, they access a digital simulation of parabolic motion as well as a virtual experiment of bullet motion, where they can determine the Earth’s gravitational acceleration g with a virtual lab using GeoGebra. The results showed that students were able to obtain a value close to 9.8 m/s^2. However, the implementation of the training faced several obstacles, including declining student attendance and motivation to learn due to various factors such as sports competitions, chapter exams, and holiday celebrations. As a result, the training could not be implemented optimally.

TABLE 3. Expert Validation Results.

Aspect assessed	Content Expert (avg)	Media Expert (avg)	Average Score	Average Category
Content Quality	3.1	-	3.0	Very Good
Language Clarity	2.7	-		
Presentation	3.0	-		
Design	-	3.4	3.2	Very Good
Ease of Use	-	3.2		
Consistency	-	3.0		
Usability	-	3.0		

The pre-test and post-test instruments were used as a tool to measure the effectiveness of the module through improved student learning outcomes. The question instrument was a multiple-choice test totalling items with four answer choices. The OSN materials evaluated include quantities, units, measurement, motion, force, effort and energy. The module's effectiveness was evaluated through a limited trial involving ten prospective OSN participants by looking at the N-Gain value. N-Gain measures how much improvement in student understanding is compared to the maximum potential improvement that might be achieved [27]. Based on the calculation shown in Table 4, the average normalized gain ($g = 0.38$) falls within the moderate effectiveness category, as defined by Hake [17]. This value was calculated based on the increase in the average post-test score against the pre-test score and was used as an indicator of learning effectiveness at the group level. Module development that had gone through limited testing on student groups regarding N-Gain criteria was declared effective.

TABLE 4 . N-Gain Scores Summary

Metric	Value	Interpretation
Pre-test Average	32.67	-
Post-test Average	58.00	-
N-Gain Average (g)	0.38	Moderate Effectiveness

The results showed an average N-gain score of 0.38, which is categorized as moderate. This finding is consistent with Febrinita (2022), who reported learning improvements with an N-gain also in the moderate category [28]. However, other studies have obtained higher results, such as Prihastuti & Sukaesih (2024), who reported an N-gain score of 0.71 when an interactive e-module was implemented over a longer period and with a larger sample size [29]. Similar outcomes have been reported in studies utilizing PhET and GeoGebra-based modules. For instance, Fatimah & Suryandari (2022) demonstrated that PhET-based virtual laboratories improved students' science process skills with moderate effectiveness, while Handika & Sasono (2021) found that GeoGebra integration enhanced students' understanding of vectors and kinematics, also yielding medium learning gains [21, 23]. These comparisons suggest that the moderate N-gain result of this study aligns with previous works employing digital simulation, while the differences in gain scores can be explained by variations in implementation duration, participant numbers, and the level of difficulty of the learning content. Thus, the moderate N-gain achieved in this study may be attributed to the limited training duration (only one month), the relatively small number of participants (10 students), and the higher level of difficulty of OSN materials compared to the regular junior high school curriculum. Nevertheless, the findings confirm that the developed module is effective in improving students' conceptual understanding and offer novelty by integrating multiple simulation platforms into a single OSN-focused resource for junior high school students, which has not been presented in prior research.

The N-gain test results indicated an improvement in students' understanding of OSN-related material learned through the module. A review of the test data showed a general increase in comprehension across topics such as measurement, linear motion, Newton's laws, and the law of conservation of mechanical energy. Observational notes taken during the training also revealed positive student responses, largely due to the support provided by interactive digital simulations, which enhanced both motivation and conceptual understanding in physics. To assess the practicality of the developed module, a test was conducted involving both teachers and students who used the module for OSN training activities. The assessment aimed to identify the extent to which the module is practical to use in OSN training and to highlight potential implementation challenges faced by users when learning the material and running interactive digital simulations within the module.

Both teachers and students evaluated the module's practicality, providing valuable insights into its usability. According to Table 5, both groups responded positively, giving very good ratings across all components of the module. The results showed that this module not only presented the material conventionally, but also provided a more interesting and in-depth learning experience through visualization and integration of interactive digital simulations. Given these findings, the module was considered practical and feasible to use in OSN IPA training at the junior high school level. Its ability to provide interactive learning experience set it apart from conventional teaching methods and made it an attractive option for educators seeking innovative ways to support their students' learning.

TABLE 5. Practicality Scores from Student and Teacher Evaluations.

Respondent	Aspect Assessed	Average Score
Teacher	Content, Language, Usability, Ease to Use	3.8
Students (n=10)	Attention, Relevance, Usefulness, Motivation	3.5

CONCLUSION

This study aimed to develop and evaluate an interactive digital module based on GeoGebra and PhET simulations to support physics training for junior high school students preparing for the National Science Olympiad (OSN), with a focus on mechanics. The developed module was validated by experts who rated it as very good in both content and media design. This indicates that the module meets the necessary standards for educational resources.

Upon implementation, the module demonstrated moderate effectiveness (N-Gain = 0.38) and high practicality, as indicated by positive feedback from both students and teachers. The integration of interactive simulations enabled students to visualize abstract concepts and engage in active learning. These findings suggested that the module was a feasible and effective tool for supporting OSN preparation and had potential for broader use in competition-based science education. By providing an engaging and interactive learning experience, the module helped students develop a deeper understanding of physics concepts and improve their problem-solving skills.

In conclusion, this study contributes to the development of innovative educational resources that support STEM education and competition-based science education. The developed module serves as a model for creating effective digital learning tools that cater to the needs of junior high school students preparing for the National Science Olympiad (OSN).

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