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Meaningful Learning with Digital Module: Innovation in High School Physics Learning on Waves

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Abstract

The development of 21st-century technology demands innovations in learning media that can support critical, creative, collaborative, and communicative thinking skills. In the context of physics learning, students often still face difficulties in understanding abstract concepts, including Wave material, due to limitations in visualization and the connection between theory and real phenomena. This study aims to develop a digital module based on Meaningful Learning in Wave material as an alternative learning medium that is more interactive, contextual, and aligned with current demands. The research employs the Research and Development (R&D) method using the Dick & Carey model to develop the digital module. Expert validation shows a very good level of feasibility with percentages of 92.5% for the media aspect, 79.2% for the material aspect, and 88.3% for the learning aspect. A limited trial involving 22 students produced positive responses with an average of 92.38%. These results demonstrate that the digital module is not only feasible for use but also effective in helping students connect prior knowledge with new concepts through concept maps, images, animations, and interactive videos. The developed digital module is equipped with concept maps, learning outcomes, illustrations, animations, and interactive videos, which have been proven to help students connect prior knowledge with new concepts, thereby supporting the achievement of meaningful learning. Thus, the digital module based on Meaningful Learning in Wave material can serve as an innovative alternative learning medium to enhance students' conceptual understanding and 21st-century skills.

Keywords: digital module, meaningful learning, waves

INTRODUCTION

21st-century learning has undergone rapid changes in various aspects of life, driven by the advancement of science and technology (Kalyani, 2024). Students are required to possess higher-order thinking skills (Rati et al., 2023; Indrasari et al., 2022), become independent learners (Hidayat et al., 2025), and adapt to an ever-changing environment (Dewi, 2024). It is no longer sufficient for students to merely memorize content; instead, they must acquire critical thinking, creativity, collaboration, communication, and technological literacy skills (Marwa et al., 2024; Bakri, 2023; Supena et al., 2021). These skills align with the competencies outlined in the 4C framework (Critical Thinking, Creativity, Collaboration, Communication), which serves as the cornerstone of 21st-century learning. The 4C competency framework is an essential foundation for designing physics learning in senior high schools.

Physics education is pivotal for developing the core scientific thinking that underpins technological progress (Bakri et al., 2021). Effective physics learning should go beyond theory and formulas to develop problem-solving, observation, and analysis skills through real-world contexts (Nurul, 2022;

Ayudha, 2021). Despite its potential to foster critical and innovative thinking, classroom physics instruction frequently relies on conventional, teacher-centered methods that hinder students' ability to relate concepts to real-life contexts (Jafar, 2021; Pertiwi, 2022; Commeford, 2021).

A needs analysis was conducted to identify the factors contributing to students' difficulties in learning physics. Findings revealed that 54.8% of 104 respondents reported difficulty in understanding abstract concepts, and 49% struggled to visualize phenomena. Students continue to face challenges in linking abstract knowledge with real-world representations. For instance, when asked to illustrate transverse or longitudinal waves, they often become confused in expressing them graphically without the correct mathematical symbols. As a result, their understanding of wave behavior, including frequency and amplitude, is often overlooked, even though both are essential in analyzing wave characteristics. Other obstacles include difficulty in understanding the relationship between theory and practice (27.9%) as well as experimental procedures in laboratory work (12.5%). This condition demands that teachers be more creative in developing contextual and interactive learning media, so that physics concepts can be more easily understood and truly meaningful for students (Miswati, 2020).

Learning media plays a vital role in supporting the effectiveness of communication and interaction between teachers and students, while also enhancing motivation, interest, and learning activities (Al-Rahmi et al., 2023; Rahim et al., 2022). Teachers need to optimize their creativity in designing and implementing learning media in accordance with curriculum demands (Gunawan et al., 2019). Learning media may take the form of traditional print media or digital-based media that leverage the latest technological advancements. The development of information technology has shifted the use of media from traditional print toward more interactive and flexible digital media. The presence of digital devices such as computers, smartphones, and the internet enables the creation of contextual, student-centered learning experiences. One of the digital learning media that is easily accessible to high school students is the digital module.

The use of digital modules as learning media has become a key innovation in supporting educational transformation in the digital era (Herliana et al., 2023). Digital modules offer high flexibility as they can be accessed anytime and anywhere through electronic devices (Wirdiyatusyifa, 2021). They also hold interactive potential through the integration of videos, animations, simulations, and automatic quizzes, which are highly beneficial in explaining abstract concepts, particularly in physics subjects (Nurlina et al., 2024; Nasbey, 2024). By utilizing technology, digital modules can create an enjoyable learning atmosphere (Vebrianto et al., 2024). However, their implementation has not yet been fully optimized. Many digital modules are still limited to static PDF formats that merely replicate printed versions, thereby underutilizing the potential of interactive multimedia. Technical obstacles, such as limited device availability and poor internet connectivity, also pose challenges, especially in areas with limited technological access, leading to learning disparities among students. Despite these challenges, needs analysis results show that 61 out of 104 respondents agreed that the use of digital modules facilitates physics learning, as they can be accessed anytime and anywhere, incorporate images, videos, and assessment links, and are designed to be attractive and engaging.

The use of digital modules can serve as a bridge that strengthens the connection between prior knowledge and new knowledge. Digital modules offer various advantages that support the achievement of Meaningful Learning (Bella-Nava, 2019). Learning becomes more effective when new knowledge can be logically linked to students' existing cognitive structures (Hanani, 2020). Meaningful Learning occurs when new information is connected with students' prior knowledge, resulting in deeper and more lasting conceptual understanding (Bryce & Blown, 2023; Andrews, 2023). Meaningful Learning can also be seen as part of Deep Learning, where students do not merely receive information passively but actively construct knowledge by linking new information with prior knowledge. This process of Meaningful Learning serves as a foundation for cultivating digital literacy, critical thinking skills, and collaboration competencies that are essential in the 21st century (Zou et al., 2025). Therefore, this study aims to develop digital learning media to support meaningful learning for students.

METHODS

Research Design

This research uses a research and development (R&D) method based on the model proposed by Walter Dick and Lou Carey (Yuwana, 2023; Dick & Carey, 2015). The process begins with identifying instructional goals as the foundation of the product being developed. Then, the researcher conducts instructional analysis to determine the components of knowledge and skills required, followed by analyzing learners and contexts to understand student characteristics and the learning environment. Based on these analyses, performance objectives are written to specify the expected learning outcomes. The next stage is to develop assessment instruments that align with the objectives, and then design an instructional strategy that guides the implementation of learning. Afterward, instructional materials are developed according to the strategy, ensuring they are structured and coherent. Finally, a formative evaluation is carried out on a limited scale to test the feasibility and initial effectiveness of the product, with the possibility of revisions if weaknesses are found. These steps ensure that the product developed is systematically designed and adapted to the actual needs of students.

Instruments and Data Collection

The research instruments used in the development of this digital module consisted of an expert validation sheet and student and teacher response questionnaires. The expert validation sheet was used to assess the feasibility of the media, materials, and learning, compiled based on specific indicators and using a Likert scale, with the results presented in TABLE 1. This instrument was given to validators who are competent in their respective fields to obtain assessments and constructive input for product improvement. The results of the expert validation served as the basis for product revisions to enhance their effectiveness and alignment with learning objectives.

TABLE 1. Likert Scale Criteria

Score	Interpretation
4	Strongly Agree
3	Agree
2	Disagree
1	Strongly Disagree

Student response questionnaires were used in both small-group and limited-trial testing to determine the level of readability, ease of use, attractiveness, and usefulness of the developed learning media. To process the data, a continuous scale interpretation technique was used, in which the variables studied were broken down into several indicators. These indicators were then used as the basis for compiling instrument items in the form of questions or statements. The instrument's feasibility value is shown in Eq. 1.

$$Score\ Interpretation\ (IS) = \frac{Score\ obtained}{Highest\ total\ score} \times 100\% \quad (1)$$

The results of these calculations are then used to determine the feasibility interpretation percentage. This percentage then serves as a reference for categorizing the module's feasibility level based on the specified interpretation range, as shown in TABLE 2.

TABLE 2. Feasibility Interpretation

Score Interpretation	Interpretation
$81.25\% \leq IS < 100\%$	Strongly Feasible
$62.50\% \leq IS < 81.25\%$	Feasible
$43.75\% \leq IS < 62.50\%$	Not feasible
$IS < 43.75\%$	Strongly Not Feasible

Digital Module Trial

The trial was conducted in two stages: a small group trial and a limited trial. The small group trial was intended to identify initial weaknesses in terms of presentation and content, while the limited trial involved 22 students to obtain a more comprehensive picture of the product's effectiveness, readability, ease of use, and attractiveness in a learning context. The results of these two trial stages served as the basis for researchers to revise and refine the product before its wider implementation.

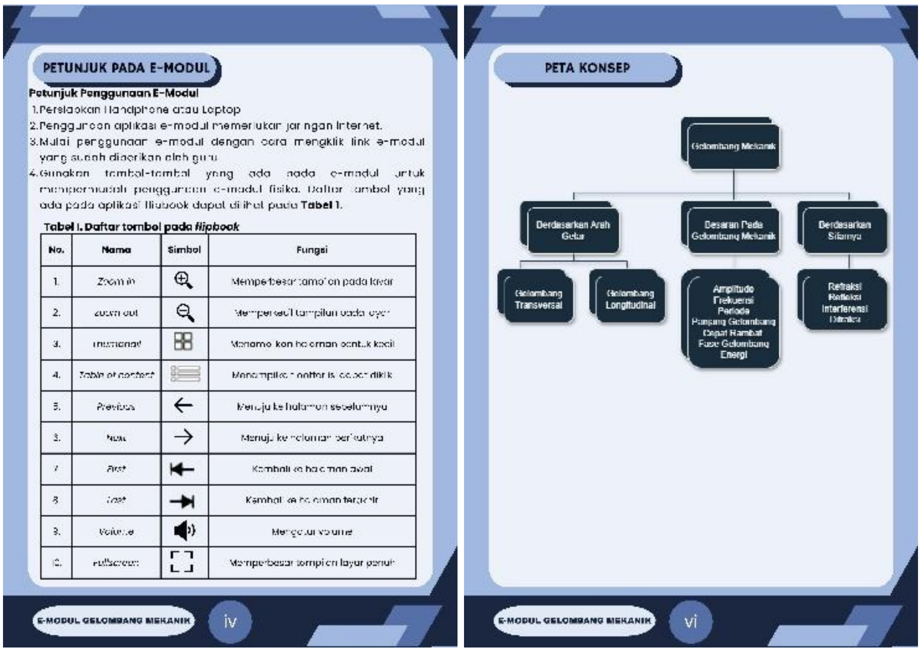
RESULTS AND DISCUSSION

Digital Module Results

The resulting research product is a Digital Module developed with a Meaningful Learning approach on the subject of Waves. This module is designed as an innovative learning medium that can be accessed independently by students to enhance their understanding of physics concepts, particularly in the context of mechanical waves. During the development process, the module design utilized the Canva application for graphic visualization and Microsoft Word for content preparation, and then published through the Heyzine platform for online access in an interactive format. The appearance of the digital module's homepage is shown in FIGURE 1.

FIGURE 1. Digital module cover

The digital module includes user manuals that serve as a guide for both teachers and students, making it easier for them to utilize the module in support of their learning objectives. These instructions cover how to access digital content, steps for participating in learning activities, and how to utilize interactive features. The digital module also includes a concept map designed to provide a comprehensive overview of the interrelationships between subtopics within the Waves topic. This concept map helps students organize knowledge, understand the learning flow, and see the relationships between concepts, making learning more meaningful. The user manual and concept map for the digital module are presented in FIGURE 2.



(a) (b)

FIGURE 2. (a) Instructions for using the digital module and (b) concept map

FIGURE 3 presents the learning outcomes of the digital module. These learning outcomes, aligned with the Kurikulum Merdeka, focus on mastering the basic concepts of mechanical waves, analyzing physical phenomena, and applying concepts in everyday life. With clear learning outcomes, students are guided to understand the competencies they should achieve after using this module.

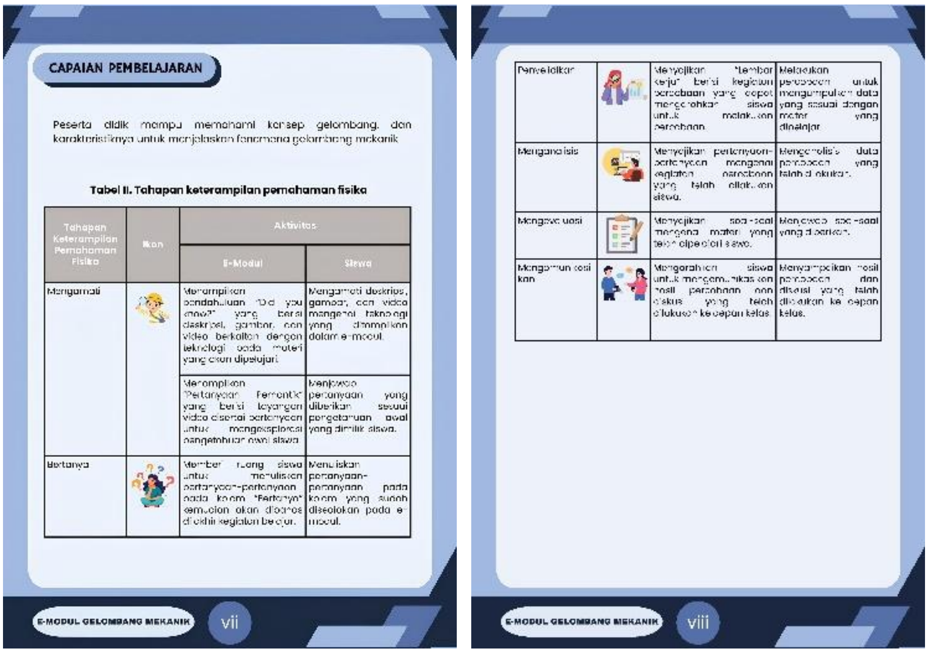


FIGURE 3. Learning Outcomes in the Wave material

The digital module comprises four learning activities, as illustrated in Figure 4. Each learning activity is systematically structured to train thinking skills and understanding of physics concepts. Each activity includes learning steps designed to encourage students to observe phenomena, analyze problems, and draw conclusions. Thus, the module serves not only as a learning resource but also as a means to practice science process skills.

FIGURE 4. Learning activities in the digital module

This digital module excels in content presentation, as it not only displays material descriptions but also includes illustrations in the form of images, animations, and instructional videos that can be played directly within the module. The presence of these visual and audiovisual media is expected to facilitate students' connection of abstract concepts with concrete representations, in accordance with the principle of meaningful learning, which emphasizes the connection between new knowledge and existing knowledge. Furthermore, the material and activities presented in the digital module have been adapted to the Independent Curriculum, ensuring that the module content is relevant to current learning needs. This adjustment is evident in the selection of content, learning objectives, and the development of learning activities that emphasize independence, active engagement, and the strengthening of student competencies. A variety of content presentations is shown in FIGURE 5.

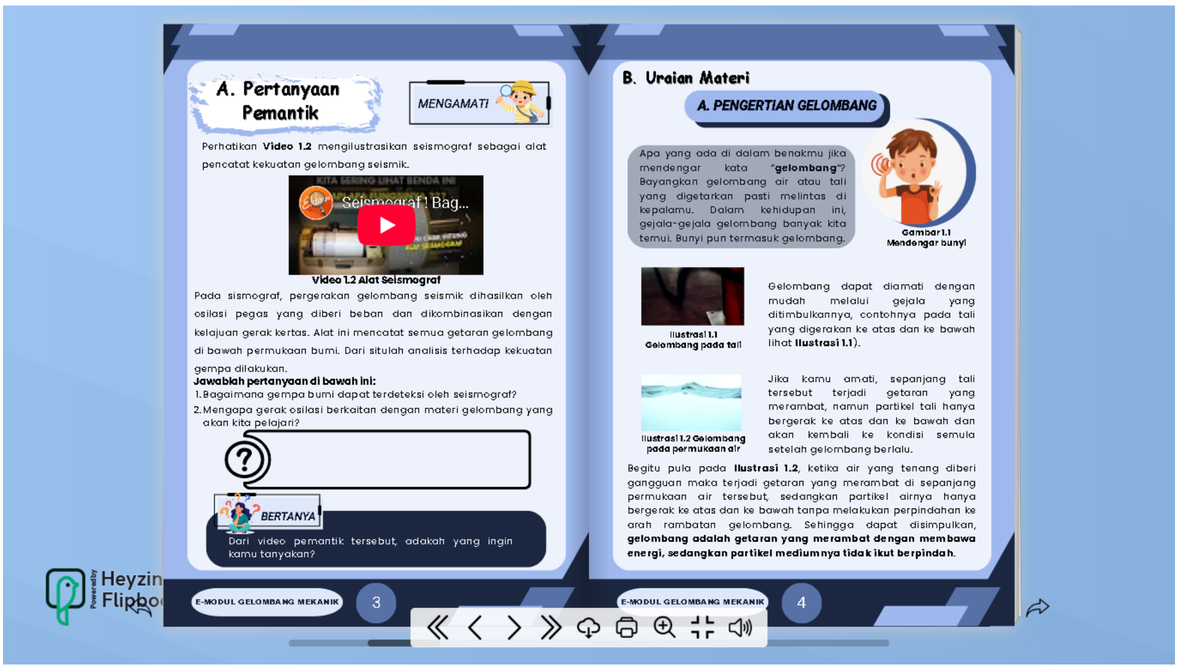


FIGURE 5. Presentation of content in digital modules

Digital Module Feasibility

The feasibility of the digital module, utilizing the Meaningful Learning approach for the Wave material, was assessed through expert validation and limited trials with students. This step was taken to ensure the module's quality, accuracy, and acceptability before its wider use in physics learning. Validation was conducted by three experts: media experts, material experts, and learning experts. The feasibility results of the digital module are presented in TABLE 3.

TABLE 3. Feasibility of Digital Modules

Feasibility Aspects	Percentage
Media Expert	
Module Components	100%
Module Appearance	87.5%
Module Characteristics	95.0%
Sentence Structure	87.5%
Subject Matter Expert	
Scope of Subject Matter	87.5%
Presentation of Subject Matter	75.0%
Sentence Structure	75.0%
Learning Expert	
Use of digital modules in learning	90.0%
Meaningful learning process	87.5%
Sentence Structure	87.5%

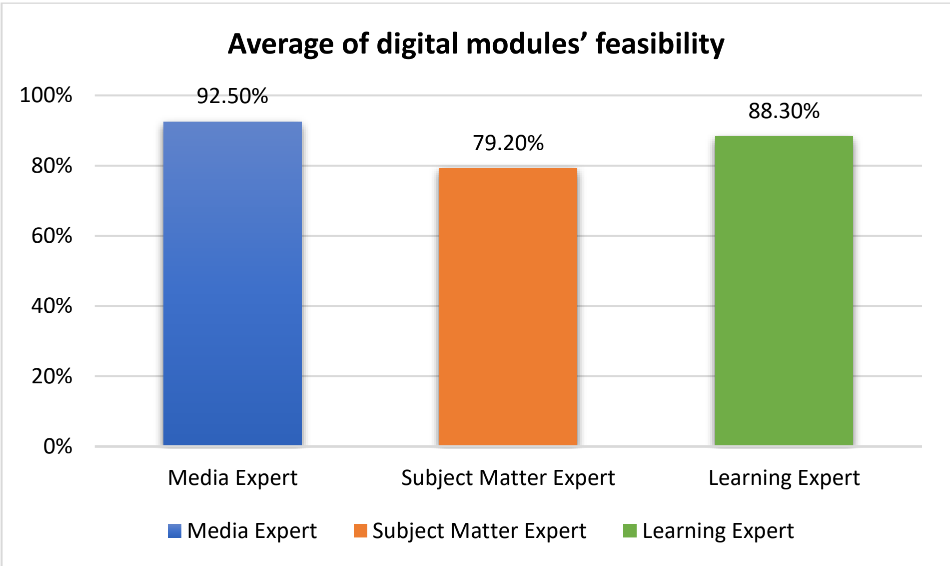


FIGURE 6. Average of digital modules' feasibility

The feasibility test results shown in FIGURE 6 indicate that the digital module received an excellent assessment from the media expert (92.50%) and the learning expert (88.30%), while the subject matter expert gave a lower score of 79.20%.In terms of media, the module received high appreciation, especially for its completeness of components, which reached 100%. This indicates that the module has presented all essential elements in accordance with the standards for developing digital teaching materials. Meanwhile, according to material experts, the module is considered adequate but requires strengthening. Two aspects that are relatively low are material presentation (75%) and word choice/sentence structure (75%). Improvements in the systematic presentation of concepts and simplification of wording are needed to facilitate understanding of abstract physics concepts.

According to learning experts, the module has facilitated the connection of new knowledge with students' initial schemas through concept maps, visualizations, and activities.

Next, the validated digital module was piloted on a group of eleventh-grade students studying mechanical waves. The pilot test was conducted by giving students the opportunity to use the module independently and then asking them to provide feedback via a questionnaire. Aspects assessed included ease of use, readability of the material, attractiveness of the display, and the module's usefulness in helping them understand physics concepts. Student responses indicated that the majority of students found the digital module easy to use, engaging, and very helpful in understanding the material, particularly because it included images, interactive videos, concept maps, and clear learning outcomes.

Following the validation process by experts, the digital module was piloted on a limited basis with 22 students to obtain direct user feedback. This pilot test involved several students using the module in learning activities. They were then asked to complete a questionnaire regarding the module's display, content, readability, ease of use, and its usefulness in understanding the material. The results of the questionnaire responses are presented in TABLE 4.

TABLE 4. Student Response Questionnaire

Student Response Questionnaire	Percentage
Digital module uses	95.45%
Digital module display	91.39%
Digital module materials	94.31%

The results of the pilot test using a student response questionnaire showed that the digital module received very positive ratings, with percentages of 95.45% for usability, 91.39% for display, and 94.31% for material. These scores confirm that the digital module is considered useful, has an attractive display, and presents relevant and easy-to-understand material. With an average percentage above 90%, it can be concluded that this digital module is very suitable for use in learning, although the display can still be improved to make it more interactive.

Discussion

The development of this digital module for the Wave material emphasizes the application of Meaningful Learning, where new information learned by students is linked to their prior knowledge and understanding. Learning will be more lasting and meaningful if new concepts are integrated with students' cognitive structures. Validation by experts confirmed that the module meets the criteria for quality digital teaching materials, although improvements are still needed in the systematic presentation of the material and the choice of editor to make it simpler and more understandable for students. This aligns with the findings of Miswati (2020), who emphasized the importance of clear language and material flow in learning media for a more effective understanding of abstract physics concepts. The results of the student response questionnaire showed a very positive level of acceptance. Average scores above 90% for usability, appearance, and content aspects indicate that the digital module is not only beneficial but also capable of increasing learning motivation. This supports Al-Rahmi et al. (2023) and Rahim et al. (2022) view that digital learning media can create engaging, flexible, and more contextual learning experiences compared to conventional print media. Research findings indicate that students who previously struggled to understand abstract wave concepts, such as frequency and amplitude, found the digital module significantly more helpful due to its use of illustrations, animations, and videos. Student needs questionnaire data also indicated that nearly 50% of students struggled to visualize abstract phenomena, making the integration of multimedia content into the digital module an effective solution. The presence of interactive features in the form of images, videos, animations, and concept maps has been shown to help students understand representations of wave phenomena that were previously difficult to visualize. These features enable students to connect real-world phenomena with scientific representations, so concepts are no longer understood in isolation but rather within an interconnected network of knowledge. Thus, the module not only conveys information but also facilitates the knowledge construction process, which is the core of meaningful learning.

The availability of learning outcomes and concept maps in the module helps students develop a framework for thinking before studying the material in more detail. This strengthens the process of integrating new knowledge into existing cognitive schemas. Learning activities are presented in stages, starting with observing phenomena and analyzing problems, and drawing conclusions, while also fostering critical thinking and science process skills. Meaningful learning occurs not only at the cognitive level but also hones students' affective and psychomotor aspects.

Furthermore, the existence of learning outcomes aligned with the Independent Curriculum further supports the module's relevance for meaningful learning, as it trains critical thinking and science process skills. This is consistent with the principle of Meaningful Learning, which connects new knowledge with students' prior knowledge.

The developed digital modules represent learning innovations that strengthen 21st-century competencies, especially in digital literacy, collaboration, and critical thinking. However, the study also noted limitations in presentation, with a need for clearer language and more interactive displays. Future research can focus on incorporating richer features, such as virtual labs or augmented reality, to further enhance the learning experience.

CONCLUSION

The digital module based on Meaningful Learning on Wave material developed in this study is considered very suitable for use as a physics learning medium in high school. The results of expert validation and limited trials indicate that the module has high feasibility in terms of media, materials, and learning, with very positive student responses, especially in terms of usability, display, and content. The integration of images, videos, animations, and concept maps has been proven to help students understand abstract concepts more meaningfully and support the strengthening of 21st-century competencies, although improvements in language presentation and increasing module interactivity are still needed for further research.

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