Phi: Jurnal Pendidikan Fisika dan Terapan
Vol. 13, No. 1 (2027) 78-93
ISSN: 2460-4348, e-ISSN: 2549-7162
https://jurnal.ar-raniry.ac.id/index.php/jurnalphi/index

Article Type: *original research*

Development of Web-Based Interactive E-Modules Using a STEM Approach to Improve Students' Science Literacy in Wave-Related Topics

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ARTICLE INFO

Article History:
Received: 04 May 2026
Revised: 19 July 2026
Accepted: 14 August 2026
Published: 22 September 2026

Keywords:
Web-based e-module; STEM approach; Science literacy; Wave material; ADDIE model

ABSTRACT

The low level of science literacy among Indonesian students and the prevalence of teacher-centered learning remain major challenges in physics education, particularly regarding wave concepts. The lack of interactive learning media that connects physics concepts to real-life phenomena further exacerbates this situation. This study aims to develop a web-based interactive e-module using a STEM approach to improve the science literacy of 11th-grade students regarding wave concepts. This study employs a Research and Development (R&D) approach utilizing the ADDIE framework (Analysis, Design, Development, Implementation, Evaluation) at State Senior High School 11 in South Tangerang during the second semester of the 2025/2026 academic year. The e-learning module was developed using Google Sites, integrating virtual laboratory simulations, interactive videos, and evaluative quizzes. Data were collected through expert validation surveys, feasibility surveys, and pre- and post-test instruments, and analyzed using N-gain analysis. Validation results showed that the e-module was rated as valid by content experts (Aiken's V = 0.79), highly valid by media experts (Aiken's V = 0.88), and highly valid by language experts (Aiken's V = 0.82). The usability test yielded a score of 84% in the small-group pilot and 81% in the field pilot by students (usable), as well as 93% by teachers (highly usable). Improvements in science literacy were demonstrated by an N-gain score of 0.58 (moderate category) among 31 students, with a pre-test average score of 13.80 and a post-test score of 63.44. It was concluded that the web-based interactive electronic module using a STEM approach is a valid, practical, and sufficiently effective learning medium for improving students' science literacy regarding wave material.

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1. INTRODUCTION

Developments in the 21st century emphasize the importance of fostering various student competencies, such as critical thinking, problem-solving, collaboration, and science literacy. In the era of Industry 4.0, the world is experiencing rapid growth in science and technology, which significantly impacts human life (Suyidno et al., 2022). These developments have brought about changes and influenced various aspects of education (Al Farizi et al., 2023). The essence of science learning is not merely accepting theories already discovered by scientists. Rather, students should be able to analyze, connect, and apply these concepts to real-life situations (Hidayatullah, n.d.). Such a science learning process can be achieved through science literacy (Afriana et al., 2016). Science

literacy requires the skills to explain various natural phenomena through a scientific approach, to develop and evaluate scientific investigations, and to critically interpret data using scientific evidence. Additionally, it involves searching for, evaluating, and applying scientific information in decision-making processes or the implementation of actions (OECD, 2025). Science literacy trains students to solve current problems related to science, technology, and social issues occurring in their environment (Amarulloh, 2022).

The 2022 PISA results show that the average scores of Indonesian students fell below the OECD average in the three areas assessed: mathematics (366, compared to the OECD average of 472), reading literacy (359, compared to 476), and science (383, compared to 485). These results are the lowest since Indonesia began participating in PISA; in fact, they match the 2003 results in mathematics and reading, as well as the 2006 results in science (OECD, 2023). The low level of science literacy in this country, as evidenced by the PISA results, highlights the need for educational reform to improve students' understanding of scientific concepts and their ability to apply them (Mashami et al., 2025). One factor contributing to students' low science literacy is the use of approaches or models that do not connect science to real-life problems. Consequently, this results in a learning process that lacks meaning and fails to encourage students to be active in the classroom (Karmana, 2024).

In the field of physics education, particularly regarding the topic of waves, students still face challenges in understanding and integrating the physics concepts they learn. For example, students often fail to distinguish between frequency and period, or to connect wave properties with real-world phenomena such as sound and light. This indicates the presence of misconceptions and a weak connection between the concepts being studied. Teachers also often fail to emphasize the essential aspects of concepts in depth, so students' understanding does not develop in a conceptual and systematic manner (Xie et al., 2021).

In addition, teaching still largely relies on the Teacher-Centered Learning (TCL) approach. The TCL approach requires learning activities to be teacher-centered (Mohamad et al., 2015a). In this approach, the teacher plays a dominant role as an information provider, while students play a passive role in the learning process (Al-Zu'be, 2013 as cited in Mohamad et al., 2015). Although the presentation of material has attempted to relate to real-world phenomena, student activities in exploring, examining, and verifying concepts remain very limited. The lecture model used does not sufficiently develop students' scientific thinking skills, even though active engagement is essential for students to build understanding through direct experience (Malina et al., 2021).

Another issue identified is the limited use of interactive learning media, which is one of the factors hindering the improvement of science literacy. The use of conventional teaching materials, such as books and one-way PDF modules, still dominates the learning process. These limitations make physics concepts difficult to visualize, rendering them less effective and even leading to boredom and a lack of enthusiasm for learning. Research by Saprudin et al. (2021) confirms that the development of interactive e-modules has been proven to improve critical thinking skills and science literacy because they dynamically integrate text, animation, and assessment.

In today's digital age, flexibility is the key to efficiency in everything, including the learning process. Web-based e-modules offer many advantages over traditional printed teaching materials or modules (Wijaya et al., 2025). Web-based e-modules encourage students to be active and interactive in the learning process. Consequently, the effectiveness of students' learning processes will improve (Firdausi & Wulandari, 2021). Additionally, web-based e-modules allow students to access learning materials flexibly, without being constrained by location or time. This fosters students' independence in learning outside the classroom. Moreover, this flexibility facilitates the implementation of various approaches in content delivery, assessment, adjustment of learning pace, and teaching methods in the development of e-modules (Ammar et al., 2024). This web-based platform offers ease of access, flexibility, and scalability, facilitating collaboration and real-time monitoring of learning progress (Liu et al., 2026). Web-based learning encourages interaction and the exchange of ideas among students with their peers, both inside and outside the classroom (Iyamuremye et al., 2024). The impact of using web-based learning enables students to be motivated in participating in learning (Sripadungkul et al., 2026).

In addition, learning activities still tend to focus on presenting theoretical concepts without integrating them with real-world problems. The topic of waves is often taught theoretically without linking its application to technology or the students' surrounding environment. In fact, a contextual approach is crucial in science education for building meaning and connections to real life. STEM plays a vital role in equipping individuals and society to address a wide range of social, economic, and environmental challenges (Siostrom et al., 2026). STEM (Science, Technology, Engineering, Mathematics) is a learning approach that enables students to connect the concepts they learn with various real-world problems (Saprudin et al., 2021). The STEM approach helps develop interdisciplinary skills, including problem-solving, critical thinking, and innovative creativity (Murphy et al., 2019).

The STEM approach does not merely focus on understanding science; rather, it enables students to enhance their critical thinking skills, creativity, and collaboration skills (Zendrato et al., 2024). The STEM approach encompasses the mastery of various skills, such as effectively understanding current scientific literature, designing a study, interpreting research findings, and communicating scientific knowledge and theories clearly and systematically (Joyner & Parks, 2023). The STEM approach can enrich students' knowledge and enable them to apply it in real-life situations (Sole, 2021). STEM education is increasingly recognized worldwide as one of the main pillars of sustainable development. Governments and international organizations have emphasized that STEM education equips young people with the critical thinking, creativity, problem-solving skills, and digital literacy they need to adapt to the ever-changing dynamics of the job market (García-Silva et al., 2026).

Challenges faced by teachers in developing and implementing science literacy-based learning and the Minimum Competency Assessment (AKM) approach. Teachers are often not yet accustomed to designing context-based or inquiry-based instructional materials and assessments that emphasize cross-conceptual understanding and scientific skills (Malina et al., 2021). Several studies indicate that teachers struggle to develop science literacy or numeracy questions because they do not yet understand their characteristics, as well as due to the limited availability of supporting media or modules that can be accessed and used flexibly (Solihudin Jh, 2018).

This issue calls for innovation through the creation of open-access, interactive, context-appropriate materials that are integrated with the STEM approach, particularly in the form of flexible, web-based electronic modules. The development of web-based electronic modules integrated with the STEM approach could be an effective solution for improving scientific understanding of wave phenomena (Syahiddah et al., 2021). However, most STEM-based learning resources still present content in only one format such as video or text without establishing clear connections between the fields of science, technology, engineering, and mathematics within an integrated learning experience (Solihudin Jh, 2018). To address this issue, this study developed a web-based interactive module. This module was specifically designed to combine virtual experiences, dynamic simulations, and context-relevant questions within the framework of the STEM approach. It is also specifically tailored to topics related to waves. This combination which is unprecedented in a single integrated web platform for this field of study is designed to enable students to transition from passively receiving content to actively conducting scientific research, thereby comprehensively strengthening their conceptual understanding and scientific literacy skills.

2. METHOD

2.1 Location and Implementation

The research was conducted at State Senior High School 11 in South Tangerang during the second semester of the 2025/2026 academic year. The subjects of this study were students in grade XI. The research was conducted from March 5 to April 30, 2026.

2.2 Research Methods and Model

The method used in this study was Research and Development (R&D), with a development model based on the ADDIE model. The ADDIE model, introduced by Branch, consists of five stages: Analysis, Design, Development, Implementation, and Evaluation (Sugiyono, 2017). The product

developed in this study is a web-based interactive e-module on wave concepts using a STEM approach, designed to support the improvement of students' science literacy skills.

The ADDIE model is a development framework consisting of five key stages: analysis, design, development, implementation, and evaluation. This research and development was conducted based on the stages of the ADDIE model proposed by (Branch, 2009):

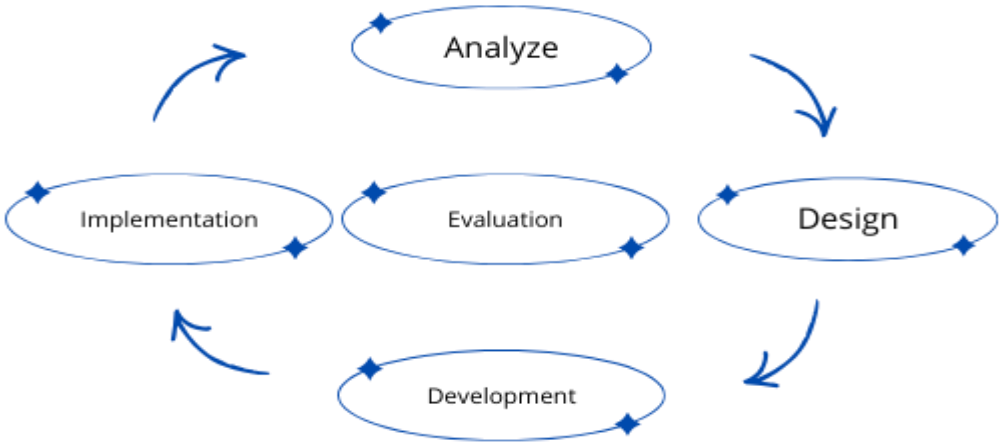


Figure 1. Stages of the ADDIE Model

2.3 Steps of the ADDIE Model

The development of web-based interactive e-modules on wave material integrated with the STEM approach in this study was conducted in accordance with the ADDIE model, as outlined in the following steps:

2.3.1 Analysis Stage

As a first step, the researcher conducted field observations to identify the conditions and learning processes taking place at the research site. Various issues that arose were identified and examined in greater depth through an analysis of student needs. The results of this analysis were then reviewed as the basis for proceeding to the next development phase.

2.3.2 Design Phase

After entering the second phase, the researchers began creating a preliminary product framework in the form of materials on wave physics, in order to determine the type of medium to be developed and to select the web platform to be used. The draft was designed in accordance with the needs identified earlier. Subsequently, the design was reviewed and evaluated to ensure its suitability before proceeding to the next phase. The researchers selected Google Sites as the platform for developing the e-module.

2.3.3 Development Phase

In this development phase, the existing design is transformed into a more concrete product. The researchers developed the media according to the planned design, then conducted validation and small-group testing. This product has been reviewed by three experts from Syarif Hidayatullah State Islamic University (UIN) in Jakarta. These three experts are a subject matter expert, a media expert, and a language expert. The subject matter expert is a professional physics education lecturer whose research focuses on science literacy, in line with this study. The media expert is a physics education lecturer involved in the development of digital learning resources. The language expert validator is a lecturer in Indonesian language and literature education and a language expert holding a doctoral degree. The involvement of validators with specialized expertise ensures the credibility and scientific accuracy of the validation process. The results of this process were analyzed to assess the product's feasibility and identify areas requiring improvement. This stage also included small-group testing to evaluate the practicality of the web-based interactive e-module on waves using a STEM approach.

2.3.4 Implementation Stage

The next stage involves implementing the revised product into classroom learning processes through field testing. During the implementation stage, data on the product's practicality is collected through student feedback surveys, while the product's effectiveness is evaluated based on improvements in students' science literacy skills.

2.3.5. Evaluation Stage

The final stage focuses on a comprehensive review of the implementation process. The researcher analyzes whether there are still any shortcomings or weaknesses in the media used. The product will be refined further if there are still components that require improvement based on the evaluation results. However, if the product meets the established criteria and does not require further improvement, the media is deemed suitable for use. Next, we examine whether students' science literacy has improved or not.

This study employed a one-group pretest-posttest design, and the implementation stages are shown in Table 1. The science literacy assessment instrument used had been validated. Instrument validation was conducted in three stages: content validity, assessed by experts to ensure the instrument aligns with science literacy indicators; construct validity, used to ensure the theoretical framework is sound; and empirical validity, conducted by administering the test to students. The test results showed that all items were deemed valid, as the correlation coefficients between each item and all other items which were recalculated had values $r > 0.344$. Furthermore, a reliability test using Cronbach's alpha yielded a coefficient of 0.86, which falls within the high reliability category. These results indicate that the instrument can be used accurately and consistently to measure students' understanding of science related to the topic of waves.

Table 1. Experimental Design: One-Group Pretest-Posttest Design

Class	Pre-test	treatment	post-test
experiment	O_1	X	O_2

2.4 Data Analysis Techniques

2.4.1 Questionnaire

This research on the development of web-based e-modules employed a questionnaire-based data collection method. Data collection in this study was conducted through questionnaires, which consisted of a student needs questionnaire, an expert evaluation questionnaire, and a questionnaire on the practicality of product use. All three questionnaires in this study were in the form of Likert scales. According to Sugiyono (2017), a Likert scale can be used to measure an individual's attitude toward a statement within a specific dimension, where respondents rate their agreement on a continuum. Generally, the Likert scale uses a score range of 1–5, with each score corresponding to a specific rating category, as shown in Table 2.

Table 2. Likert scale

Statement	Score
Strongly Agree (SS)	5
Agree (A)	4
Somewhat Disagree (SD)	3
Disagree (D)	2
Strongly Disagree (SD)	1

The expert validation questionnaire is used as an instrument to evaluate product feasibility based on expert assessments. According to Sugiyono (2013), product feasibility can be determined based on the percentage of questionnaire results analyzed using Equation 1 and the product feasibility criteria in Table 3.

$$V = \left(\frac{\sum s}{n(c-1)}\right) \quad (1)$$

Table 3. Product feasibility criteria

Value	Category
0.81–1.00	Highly Eligible
0.61–0.80	Acceptable
0.41–0.60	Fairly Acceptable
0.21–0.40	Unacceptable
<0.21	Very Unacceptable

The practicality questionnaire was used to determine how practical this web-based interactive e-module with a STEM approach is. The practicality of the product can be determined using Equation 2 and the product practicality criteria in Table 4 (Suwarna, 2016).

$$NP = \left(\frac{\sum Xi}{Xmax}\right) \times 100\% \quad (2)$$

Table 4. Product practicality criteria

Percentage	Category
86–100%	Very Practical
76–85%	Practical
60–75%	Fairly Practical
55–59%	Not Practical
<54%	Very impractical

2.4.2 N-gain

N-gain is used to measure the extent of improvement in students' abilities by comparing normalized pretest and posttest scores. The effectiveness of web-based e-modules integrated with the STEM approach can be determined through n-gain calculations, which illustrate the improvement in students' science literacy between the beginning and end of the learning process. The n-gain value can be obtained using Equation 3 and the n-gain criteria in Table 5 (Hake, 1998).

$$g = \frac{\text{post test} - \text{pre test}}{\text{maximum score} - \text{pre test}} \quad (3)$$

Table 5. N-gain Value Criteria

N-Gain	Category
0.7 ≤ Gain ≤ 1.00	High (effective)
0.3 ≤ Gain ≤ 0.7	Medium
Gain ≤ 0.3	Low

3. RESULTS AND DISCUSSION

3.1 Needs Analysis

The needs analysis was derived from a questionnaire completed by students via Google Forms. The questionnaire was completed by 31 students at State Senior High School 11 in South Tangerang. The needs analysis questionnaire included 5 indicators and 29 statements. The results of the students' needs analysis are presented in Table 6.

The data presented in Table 6 show that the identified needs are generally in the high category. This indicates that addressing students' learning needs will enhance their understanding of wave physics concepts, science literacy, and problem-solving skills. Additionally, students also expressed interest in the STEM approach and the use of web-based interactive e-modules to facilitate and improve the learning process.

This conclusion aligns with various international studies highlighting a significant gap between students' current science literacy competencies and the demands of modern physics instruction. Asrizal et al. (2023) revealed that students' literacy competencies tended to be very limited prior to the implementation of STEM-based digital physics teaching materials. This situation underscores the importance of innovation in creating contextual learning tools that can adapt to technology. On the other hand, research by Le et al. (2022) shows that the use of a digital STEM

learning environment integrated with virtual laboratories can enhance students' conceptual understanding far more effectively than traditional methods. Therefore, this series of studies provides a solid theoretical foundation for the urgent need to develop web-based interactive electronic modules in the context of this study.

Table 6. Results of student needs analysis

Indicator	Percentage	Category
Interest and Attitude toward Physics	71%	High
Understanding of Wave Concepts	66%	High
Science Literacy Skills in Wave Material	71%	High
Need for STEM-Based Learning	74%	High
Need for Web-Based Learning Media	77%	High

3.2 Design

In this design phase, the researcher determines the media or platform to be used for the development of a web-based interactive wave e-module using a STEM approach that is accessible on all devices, such as laptops, tablets, and smartphones. The design process begins with the adaptation of the learning outcomes to be implemented and the scope of the material. Media such as videos, animations, and photos were also collected. Subsequently, interactive digital platforms were selected, including YouTube, animations, Wayground, and Phet Simulation.

One user-friendly platform for developing accessible, web-based interactive e-modules is Google Sites. This is because Google Sites supports various digital media platforms, making web-based e-modules on waves even more interactive. This makes it easy to incorporate a STEM approach into these web-based e-modules, especially when dealing with the abstract concept of waves. The use of Google Sites as the primary platform for development is supported by various international studies showing that web-based platforms are capable of effectively integrating multimedia elements. This integration has been proven to enhance the interactivity and accessibility of digital learning materials for diverse groups of students (Asrizal et al., 2023).

Once all the learning materials were collected, each component was integrated into Google Sites in a structured manner. The resulting e-module was designed to create a more engaging learning environment and encourage active student participation. The features included are also intended to facilitate the use of this web-based interactive e-module on waves. The features found in the web-based interactive e-module with a STEM approach include a Home page, Navigation buttons, Introduction and User Guide, Learning Outcomes, Learning Objectives, Learning Objective Flow, Concept Map, Materials, Interactive Quizzes, Simulations or virtual labs, interactive videos, evaluation quizzes, and so on. The integration of PhET simulations as a virtual laboratory in this electronics module plays a very important role, as these simulations provide dynamic visualizations that make abstract concepts about waves more concrete. This aligns with the findings of Banda and Nzabahimana (2023), who demonstrated that learning supported by PhET simulations significantly improves the academic achievement and learning motivation of high school students in the subject of oscillations and waves. This effectiveness is reinforced by a large effect size (Cohen's d = 1.14), which proves that PhET successfully bridges the gap between abstract physics theory and students' conceptual understanding.

3.3 Development

The design of the existing development was carried forward to the development phase, resulting in a concrete product in the form of a web-based interactive e-module on waves using a STEM approach. The product was then validated by three expert validators, including a content expert, a media expert, and a language expert. All three expert validators were from the same institution, namely UIN Syarif Hidayatullah Jakarta. The feasibility of the developed product was evaluated based on the validation results from the experts. The data from the assessments by the content expert, media expert, and language expert are presented in Table 7, Table 8, and Table 9.



Figure 2. Web homepage



Figure 3. Web User Guide Page

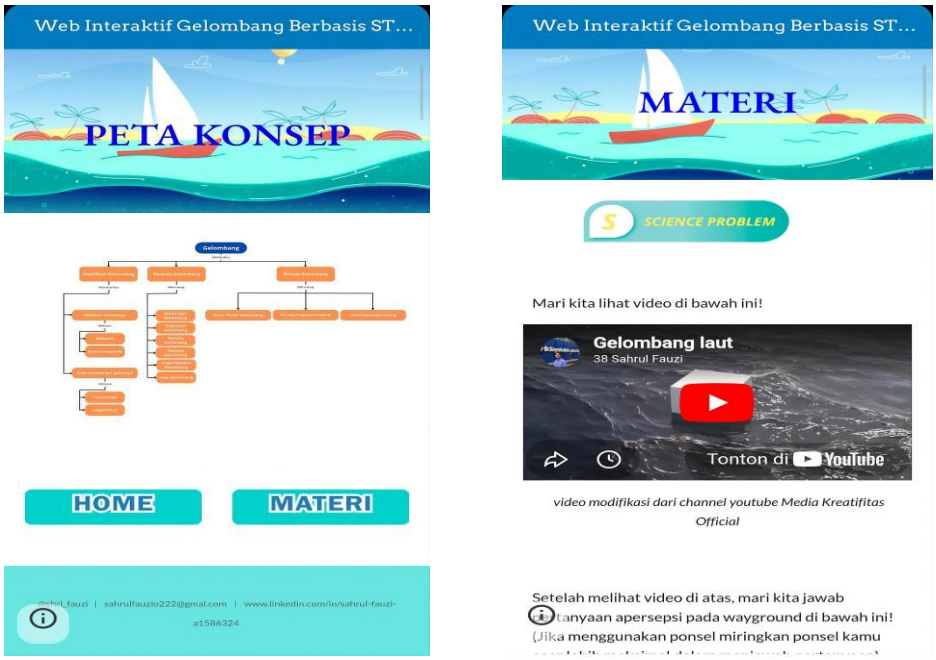


Figure 4. Concept map and materials page



Figure 5. Virtual lab and interactive assessment page

The results of the subject matter expert validation in Table 7 show four aspects: the aspect of content alignment with learning objectives and the curriculum received a score of 0.75, categorized as Valid; the aspect of the STEM approach received a score of 0.85, categorized as Very Valid; the aspect of science literacy competencies received a score of 0.80, categorized as Valid; and the aspect of Scientific Accuracy and Contextual Relevance received a score of 0.75, categorized as Valid. Thus, the overall expert material score is 0.79, categorized as Valid. Consequently, this web-based interactive e-module on waves using the STEM approach is suitable for pilot testing. The revisions provided by the subject matter experts, which involve adjustments to the concept map and the formulation of learning objectives, need to be refined. These validation results are consistent with

previous studies showing that STEM-based digital physics learning materials are considered valid across all dimensions including content, integration with STEM subjects, and science literacy aspects based on expert assessments. This conclusion reinforces that a content validation process covering various aspects is a crucial tool for ensuring quality in the design of digital learning media that integrates STEM disciplines (Asrizal et al., 2023).

Table 7. Results of the subject matter expert evaluation

Aspect	Aiken's V	Category
Alignment of Materials with Learning Objectives and Curriculum	0.75	Valid
STEM Approach	0.85	Highly Valid
Science Literacy Competence	0.80	Valid
Scientific Accuracy and Contextual Relevance	0.75	Valid
Average	0.79	Valid

Table 8. Results of the media expert assessment

Aspect	Aiken's V	Category
Visual Appearance and Interface Design Aspect	0.81	Very Valid
Navigation and Usability Aspects	0.90	Very Valid
Interactivity and Media Functionality Aspects	0.92	Very Valid
Average	0.88	Highly Valid

The results of the media expert validation in Table 8 show three aspects: the visual appearance and interface design aspect received a score of 0.81, categorized as “highly valid”; the navigation and usability aspect received a score of 0.90, categorized as “highly valid”; and the media interactivity and functionality aspect received a score of 0.92, categorized as “highly valid.” Consequently, the overall media expert score was 0.88, categorized as “highly valid.” Based on the validators’ assessment, the developed product has met the established standards and is suitable for implementation in pilot testing. The revisions provided by the media expert include adjusting the colors of the buttons and text to ensure sufficient contrast, increasing the font size on the buttons, and citing the image sources. The high validity scores obtained in the dimensions of visuals, navigation, and interactivity are consistent with international standards for web-based STEM learning media, as emphasized by Banda and Nzabahimana (2023), who state that the effectiveness of digital physics learning tools depends heavily on interface accessibility, interactivity, and visual quality to foster student engagement with abstract scientific phenomena.

Table 9. Results of the linguists’ assessment

Aspect	Aiken’s V	Category
Linguistic Accuracy	0.83	Highly Valid
Sentence Structure	0.83	Highly Valid
Clarity and Appropriateness of Language	0.79	Valid
Average	0.82	Highly Valid

The results of the linguistic validation in Table 9 show three aspects: the linguistic accuracy aspect received a score of 0.83, categorized as “highly valid”; the sentence structure aspect received a score of 0.83, categorized as “highly valid”; and the clarity and appropriateness of language aspect received a score of 0.79, categorized as “valid.” Consequently, the overall subject matter expert score

was 0.82, categorized as "highly valid." Based on the validation results, the web-based interactive e-module using a STEM approach for the topic of waves meets the established criteria and can proceed to the implementation phase through product testing. The revisions suggested by the language expert include simplifying some theoretical explanations and revising the sentences in the questions to avoid word repetition.

This development phase also includes a small-group pilot test of the web-based interactive e-module on waves using a STEM approach that is currently under development. This small-group trial was designed to identify weaknesses in the product currently under development and to assess the practicality of this web-based interactive wave e-module, using a questionnaire distributed to students after the trial. The small-group trial was conducted in the 11th grade at State High School 11 in South Tangerang, involving 6 students as shown in Table 10.

The results of the practicality questionnaire in Table 10 yielded an overall score of 84%. This score falls into the "practical" category. The feedback or suggestions provided by students generally indicated that the quizzes in this web-based, wave-themed interactive e-module using a STEM approach are cut off when opened on a mobile device or smartphone in portrait mode and take a long time to load when the signal is poor. This practical challenge is consistent with the findings of the international literature, which consistently identifies limitations in mobile device capabilities and connectivity as the primary technical barriers to the implementation of web-based digital learning resources, particularly in developing countries (Banda & Nzabahimana, 2023).

Product revisions were made based on validation results from experts and feedback from users namely teachers and students to improve the quality of the developed e-modules. As shown in Figures 2–5, the revised web-based interactive e-modules on waves using a STEM approach are now ready for implementation.

Table 10. Small-group practicality

Respondents	Total Score (Maximum score 115)	Practicality Percentage	Category
1	111	97%	Very Practical
2	90	78%	Practical
3	91	79%	Practical
4	93	81%	Practical
5	110	96%	Very Practical
6	87	76%	Practical
Average		84%	Practical

3.4 Implementation

The implementation phase involves testing the developed product in a school setting or conducting a field trial. After being revised based on feedback from subject matter experts, media experts, language experts, and students, this web-based interactive e-module on waves using a STEM approach was directly implemented in a school setting. The subjects of the field trial were 11th-grade students at State High School 11 in South Tangerang. In the field test, two instruments were used: a test instrument and a non-test instrument. The test instrument was used to assess improvements in students' science literacy through n-gain. The non-test instrument was used to evaluate the practicality of this web-based interactive e-module. The results of the product's practicality as assessed by students in the field test are shown in Table 11, and the results of the practicality assessment by teachers are shown in Table 12.

The results of the practicality test in the field trial involved 30 students, as shown in Table 11. Overall, the practicality test received a score of 81%, falling into the "practical" category. The feedback provided indicated that students found it easier to understand the abstract concept of waves. However, accessing the web-based interactive e-module took a considerable amount of time if the internet connection at the location was unstable. At the site, the internet was indeed unstable because the classroom was on the second floor and soundproof, which affected the internet connection. Therefore, Wi-Fi assistance was required. The results of this study are consistent with

the global literature, which often identifies internet connectivity issues as the most critical technical barrier to the implementation of web-based STEM learning materials, particularly in developing countries (Banda & Nzabahimana, 2023). Despite these challenges, students' positive responses regarding the enhancement of their understanding of wave concepts align with the findings of Asrizal et al. (2023). That study confirmed that the use of digital physics teaching materials integrating STEM concepts proved effective in boosting students' conceptual mastery when tested directly in the classroom.

Table 11. Field test practicality by students

Category	Amount
Very Practical (85-100%)	14 students (46.7%)
Practical (70-84%)	7 students (23.3%)
Fairly Practical (55-69%)	8 students (26.7%)
Very Impractical (<55%)	1 student (3.3%)
Average	81% Practical

The results of the practicality test conducted by professional physics teachers, as shown in Table 12, yielded a score of 93%, falling into the "very practical" category. Feedback from the physics teachers indicated that this web-based interactive e-module facilitates the learning process for both teachers and students. The digitization of education is also driven by this web-based interactive e-module and is in line with the current era. Furthermore, the STEM approach can help students better understand wave concepts, as the learning process connects wave material to everyday phenomena students frequently encounter such as the sound of an ambulance siren still being heard even when obstructed by buildings, the echo when shouting in a large building, and so on. This indicates that these web-based interactive e-modules are practical for use in the learning process. Thus, this study aligns with previous research showing that digital media using a STEM approach are highly practical for learning (Handayani, 2021).

Table 12. Teachers' Perceptions of the Practicality of Field Tests

Respondents	Total score (Maximum score 75)	Practicality Percentage	Category
Teachers	70	93	Very Practical

3.5 Evaluation

This evaluation stage reviews the feedback received from students and physics teachers, which was then refined by the researcher. Additionally, the researcher observed an improvement in students' science literacy from before they used the web-based interactive wave e-module with a STEM approach to after using it. This study employed a one-group pre-test post-test design. Thus, it involved only one class as the experimental group. The researcher observed an increase in students' science literacy based on the n-gain values obtained in Table 13.

The results of the average N-gain calculation involving 31 students are presented in Table 13. Of the 31 students, the average pre-test score was 13.80, while the average post-test score was 63.44. This resulted in an N-gain of 0.58, which falls into the moderate category. This calculation is consistent with Hake (1999).

Table 13. N-gain Result

Number of Students	Average pre-test score	Average post-test score	Maximum score	Maximum Pre-test Score	N-gain
31	13.80	63.44	100	86.20	0.58
Category	Medium				

The average N-gain score of 0.58 indicates that the use of web-based interactive e-modules contributes to improving students' science literacy skills regarding wave-related material. The fact

that the improvement did not reach a high level does not diminish the effectiveness of the developed e-module, as the product is still capable of promoting improvements in students' science literacy skills regarding wave-related material. This is due to the well-organized and interactive nature of student learning, as well as the use of the STEM method. Through the STEM approach, the learning process is always linked to Science, Technology, Engineering, and Mathematics. Consequently, the theories studied are easily understood by students, as learning is connected to real-life phenomena. The success of this electronic module in improving student learning outcomes is consistent with scientific research conducted by Asrizal et al. (2023) on the effectiveness of digital physics learning materials integrated with the Science, Technology, Engineering, and Mathematics (STEM) approach. Through this approach, complex physics concepts are explained in the context of real-world situations, enabling students to rapidly develop their knowledge and mastery of the material. In the context of the learning experience, this moderate level of cognitive growth confirms that the in-class intervention was implemented optimally and meaningfully.

This improvement in science literacy through STEM learning is consistent with previous research. Previous studies have shown that learning processes using a STEM approach have a positive impact on improving science literacy competencies (Sakti et al., 2022), and that digital physics learning materials integrated with STEM effectively help students understand complex concepts in real-world contexts (Asrizal et al., 2023).

More specifically, the N-gain score of 0.58 obtained in this study is consistent with findings from previous research on STEM-based digital learning media. Hutomo et al. (2022) demonstrated that STEM-based electronic modules consistently produce moderate improvements in science literacy among junior high school students. A similar trend was also observed in studies utilizing Google Sites as an interactive learning platform: Johdi et al. (2024) reported an N-gain value of 0.74 for wave-related material at the high school level, while Putra and Parmiti (2026) obtained an N-gain value of 0.54 in science instruction at the elementary school level. The N-gain of 0.58 in this study falls within that range, confirming that web-based interactive e-modules integrating a STEM approach are effective and comparable tools for improving students' science literacy, particularly in the context of wave-related topics.

The interpretation of these research findings must take into account several technical limitations. First, a limitation of this study is that all subject-matter experts, media experts, and language experts were from the same institution, namely UIN Syarif Hidayatullah Jakarta. This homogeneity may have limited the diversity of perspectives in the validation process. It is recommended that future research involve validators from various institutions to enhance the objectivity and comprehensiveness of the assessment. Second, the use of a one-group pretest-posttest design without a control group limits causal conclusions, as improvements in students' science literacy may be influenced by factors other than the web-based electronic module, such as natural learning progression, teacher guidance, or other academic activities. To strengthen the evidence of causality in future research, the research methodology needs to be improved by implementing a quasi-experimental or pure experimental design that includes a control group.

4. CONCLUSION

The implementation of web-based e-modules developed using a STEM approach has a positive impact on improving students' science literacy skills regarding wave-related material. The results of the needs analysis revealed that students have a strong need for education on waves in physics, which can deepen their knowledge of science literacy concepts and skills, supported by interactive online teaching resources. This web-based interactive e-module using a STEM approach can be considered valid based on the results of expert validation, with an Aiken's V score of 0.79 (valid) from content experts, 0.88 (highly valid) from media experts, and 0.82 (highly valid) from language experts. Practicality test results indicate that the web-based interactive e-module has a good level of practicality. This is demonstrated by a student response rate of 84% in the small-group test and 81% in the field test, as well as a teacher response rate of 93%, which falls into the "highly practical" category.

The results of the implementation show that the use of web-based interactive e-modules on waves using a STEM approach can improve students' science literacy. This improvement is reflected

in an N-gain score of 0.58, which falls into the moderate category. Therefore, these web-based interactive e-modules on waves using a STEM approach can serve as a viable, practical, and effective alternative teaching medium for improving students' science literacy.

However, to refine these findings, future research should focus on several key points. Expanding the use of multimedia resources to various geographic regions and schools with diverse characteristics is essential to test the applicability of this model beyond the context of a single school. Additionally, increasing the sample size in future studies will strengthen the statistical power of the data obtained. From a methodological perspective, it is highly recommended to use a quasi-experimental or pure experimental design involving a control group so that the causal effects of using web-based interactive e-modules with a STEM approach on students' science literacy can be measured more accurately. It is hoped that these developmental steps will provide a comprehensive analysis of the true potential of this digital learning medium.

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