Volume 10 Number 3, December 2025, pp. 374-388
P-ISSN:2477-7935
E-ISSN: 2548-6225
DOI: 10.59052/edufisika.v10i3.47537

DEVELOPMENT OF STEM-BASED E-MODULE ON SOUND WAVES TO IMPROVE HIGH SCHOOL STUDENTS' PROBLEM-SOLVING SKILLS

Mutiara Dier[1], Miftahul Jannah Ritonga [1], Zulkifli [1], Azizahwati[1]
[1] Universitas Riau, Riau, Indonesia
Corresponding author email: azizahwati@lecturer.unri

Article Info
Received:
Accepted:
Publication:

Abstract :
This study aims to develop a physics e-module on sound waves in Science, Technology, Engineering, and Mathematics (STEM) to enhance high school students' problem-solving skills. Researchers are not only generating digital learning products; they are also responsible for introducing innovations, such as incorporating STEM structures into problem-solving skills. The novelty of this study lies in the use of STEM, which is not oriented toward material alone but toward a set of scientific thinking operations: defining real-life problems, processing scientific ideas, planning technological outcomes, and mathematically assessing the results. The research method used was Research and Development (R&D) with the ADDIE (Analysis, Design, Development, Implementation, Evaluation) development model. The resulting product was tested for validity by material, media, and pedagogical experts, and for practicality by teachers and students. Validation results showed that the e-module is highly valid, with an average score above 3.26 across all aspects. At the same time, the practicality test indicated that it is very easy to use and effective in supporting the learning process. The research results demonstrate that this STEM-based e-module can guide students in understanding the concept of sound waves in context, developing critical and reflective thinking, and systematically improving problem-solving skills. Thus, the main contribution of this research is presenting an e-module development model that utilizes STEM as a methodological framework for problem-based learning on abstract physics material, which has not been widely applied in previous research.

Keywords: E-Module, Problem-Solving Skills, STEM

INTRODUCTION

Education in Indonesia is currently directed toward shaping students who are not only cognitively intelligent but also capable of critical thinking, creativity, and global competitiveness. This aligns with the direction of the Merdeka Curriculum, developed by the Ministry of Education, Culture, Research, and Technology (Kemendikbudristek, 2021). The Merdeka Curriculum emphasizes the importance of differentiated, interdisciplinary, and contextual learning, aiming to cultivate the six dimensions of the Pancasila Student Profile, which include critical reasoning and contextual problem-solving skills (Kemendikbudristek, 2022).

A perfect learning curriculum is not just centered on memorization but also prepares students to investigate scientific thinking and solve real-world problems with project-based learning. In this context, the STEM (Science, Technology, Engineering, and Mathematics) approach is a highly valid learning strategy, as it emphasizes the integration of cross-disciplinary knowledge to solve everyday problems scientifically and creatively (Kemendikbudristek, 2021).

In the previous implementation of the 2013 Curriculum, one of the objectives of physics learning according to Regulation of the Minister of Education and Culture (Permendikbud) No. 59 of 2014 for senior high schools (SMA/MA) was that students should not only master physics concepts and principles but also prioritize the development of positive attitudes in the learning process. To achieve this, understanding basic physics concepts becomes a very important initial step. As stated by Arifin et al. (2021) understanding basic concepts is the key for students to be able to study physics more deeply.

However, in practice, various problems arise in physics learning. One of the most common issues is the low level of students' understanding of the material being taught, as well as weak collaboration in the learning process. This condition indicates that the curriculum objectives have not been fully achieved, as there are still fundamental obstacles that need to be addressed.

In line with this, in implementing the Merdeka Curriculum, conceptual understanding is made the primary indicator for assessing learning outcomes, particularly in physics subjects. With good conceptual understanding, students can interpret physics knowledge more concretely, apply it in everyday life, and at the same time develop problem-solving skills (Szabo et al., 2020). However, low mastery of physics concepts persists due to the material's abstract nature and students' misconceptions.

One of the most challenging topics in physics is sound waves, which are abstract and dynamic. Limited media and teacher learning methods make it difficult for students to learn materials such as frequency, wavelength, resonance, and the Doppler effect. Firmansyah et al. (2022) stated physics learning is still text-focused and cannot provide active learning experiences. As a result, students have difficulty developing critical thinking and problem-solving skills.

Most students still have misconceptions, particularly regarding Newton's laws. Student attitudes showed that 29% of students were not interested in allocating additional time to study and enjoy physics. These data demonstrate a relationship between conceptual understanding and attitudes toward learning, with a correlation of 0.420 indicating a positive relationship (Rizkita & Mufit, 2022)

The research data is supported by additional data showing that, in the conceptual understanding test, the percentages of results for each indicator were: interpreting 75%, giving examples 73%, classifying 26%, comparing 14%, and explaining 61%. The data show that the indicator reflects the highest value, and the indicator shows the lowest value. It is concluded that students understand the meaning of a concept better when comparing the material to each other (Riwanto et al., 2019)

Factors contributing to students' low conceptual understanding include frequent memorization of formulas, lack of student interest, difficulty manipulating equations with more than two variables, and weaknesses in problem-solving. This is evidenced by the fact that 35% of students learned the material on vibrations and waves in the moderate category.

Helping students understand the material on motion and waves is difficult due to limited resources and the infrequent use of direct experiments. This is evidenced by data showing that 87.5% of students considered these limitations to be factors that hindered their understanding. Therefore, physical learning requires sound strategies, facilities, and project-based learning opportunities (Mahombar, 2024).

An innovative solution to address this problem is the development of STEM-based e-modules. E-modules are digital teaching media provided in a systematic, interactive, and accessible manner. STEM-integrated e-modules can connect physics theory with real-world applications, encouraging students to engage in scientific inquiry and problem-solving (Darojat & Zakirman, 2024).

Research by Yunita (2024) demonstrates that the STEM-based physics e-module on sound waves has been validated by experts and practitioners and is considered highly valid and usable in the classroom. The module presents experimental activities, interactive simulations, and problem-solving projects, thereby improving conceptual understanding and problem-solving skills. This is supported by research by Ainy (2024), who developed a STEM-based e-module using digital flipbooks, which proved effective and could improve students' problem-solving skills.

Research by Susanti (2023) demonstrated consistent results. Kiswanda et al (2021) integrated a STEM approach with SDGs issues in global warming and thermodynamics. Syarah Syahiddah et al (2021) applied the ADDIE model to the Anyflip application to develop sound materials. Rana et al (2023) applied FlipBuilder to optical instrument materials. Rasyid &Wiyatmo (2024) developed a PBL-based e-module using Canva. Research by Susanti et al (2023) developed an Android-based STEM e-module on fluid dynamics. Furthermore, research by Simbolon et al (2023) and Fauziah et al (2022) developed a 4D model e-module for junior high school students, all of which demonstrated good validity and practicality.

Students need to develop problem-solving skills in physics so that they understand the concepts more deeply and practically. Problem-solving requires analyzing situations, identifying relevant variables, formulating strategies, and evaluating solutions. According to Yulianti (2018) Problem-solving is a complex process combining conceptual understanding, logical reasoning, and critical thinking to address contextual problems. Referring to Purnama (2021) problem-solving skills involve stages of understanding the problem, planning solutions, implementing strategies, and evaluating results.

Although past researchers have already developed e-modules on physics learning using STEM, they tend to focus more on misconceptions associated with fluid dynamics, thermodynamics, and optics. Several studies have developed STEM-based e-modules on sound waves that require visual media to facilitate conceptual learning. In the meantime, not all e-modules are yet sufficient for the presentation and evaluation of content, and not all optimal ways to jump-start the engineering constituents that support problem-solving in the 21st century are included. The effect of this situation is research discrepancies that should be resolved by creating STEM-based physics e-modules aimed at enhancing students' problem-solving skills.

Thus, there is an essential requirement to develop STEM-based e-modules on sound waves to support independent curriculum in the 21st century and equip students with 21st-century skills. The e-modules that are integrated with STEM not only focus on conceptual elements that may be missing, but also enable a student to handle real-world problems in a creative and critical way (Hamid & Alberida, 2021; Herawati & Muhtadi, 2018; Padwa & Erdi, 2021; Zulaiha & Kusuma, 2020)

E-modules refer to digitized teaching resources created in an interactive, organized manner. These are in audio, visual, and animated formats, which lead to better comprehension of learning and learning skills by students (Herawati & Muhtadi, 2018). In the meantime, digital literacy may be enhanced, and meaningful learning can be promoted with regard to inquiry-/project-based e-modules (Asmiyunda et al., 2018; Padwa & Erdi, 2021). It is deemed feasible, convenient, and correlates with the traits of the online age to create the e-modules being built with the assistance of flipbooks or other applications (Hamid&Alberida, 2021; Saputra, 2024). Consequently, active, practical, and independent learning in the digital age can be facilitated by e-modules.

STEM (Science, Technology, Engineering, and Mathematics) is a learning model that connects scientific and mathematical concepts with real-world applications of technology and engineering. Learning that revolves around STEM aids students in thinking critically, and also resolves issues through cooperative learning (Roslina et al., 2025; Zulaiha & Kusuma, 2020). The STEM model makes students active contributors to project-based exploration and experimentation, which leads to a better command of the idea and 21st-century competencies (Asrizal et al., 2023; Dywan & Airlanda, 2020; Wahyuni, 2021). The STEM strategy is effective in ensuring a more contextual, meaningful, and challenging learning environment for students.

Problem-solving skills are those associated with locating, examining, and resolving problems in a systematic manner through critical and theoretical thinking procedures. The skill is an essential part of physics education since a student must be able to connect abstract material to the real world and solve problems in a context (Aripin et al., 2021; Hibatullah et al., 2024; Sitinjak, 2022). Problem-based learning model has been effective in educating the students to represent problems, create solutions alone, and analyze information (Firmansyah et al., 2022; Lismawati et al., 2024). Good problem-solving skills are identified as the skill of students to process information, to think, and to make a sound decision (Rizkita & Mufit, 2022).

The authors of the study were interested in creating a physics e-module on sound waves for eleventh-grade high school students. The e-module, which is STEM-based, covers science, technology, engineering, and mathematics. The research was not aimed at measuring the long-term effectiveness of the e-module and comparing it with other learning modules, but at its validity, practicality, and ability to enhance students' conceptual sense and problem-solving.

Given the background above, the research problem will be to develop a valid and practical physics e-module for a STEM learning medium. The module, based on STEM, is intended to support students in learning about sound waves and, at the same time, to train them in solving real-life problems.

RESEARCH METHOD

Research Design

The research method used was development (R&D) to create a STEM-based physics e-module on sound waves to improve high school students' problem-solving skills. The ADDIE model used consisted of Analysis, Design, Development, Implementation, and Evaluation (Ibrahim, 2011; Safitri&Aziz, 2022). The research steps followed these five aspects, as shown in the flowchart in Figure 1.

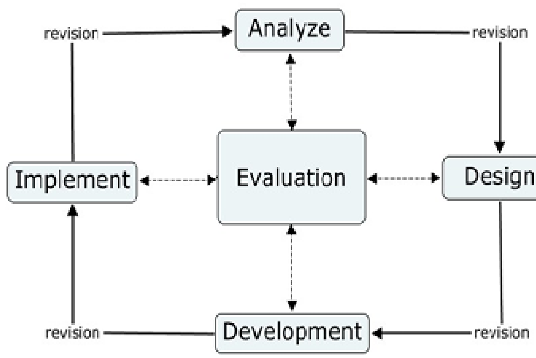

Figure 1. Research procedure flowchart (Nasir & Fakhruddin, 2023)

The ADDIE model is used to ensure that development stages are well structured and revised continuously. However, the present study was limited only to the validity and practicality testing stages. The implementation and evaluation of learning effectiveness were not carried out, as the main focus of this research was to produce and validate a valid and practical STEM-based e-module

Research Target/Subject

This study is limited to the validity and practicality testing stages. Validity was tested on three experts: a content expert, a media expert, and a technical expert. Practicality was tested on physics students and teachers

Research Procedure

Analysis

The analysis step was conducted to identify student needs, characteristics, and learning objectives, and to analyze the curriculum and materials. Data collection was conducted through interviews with physics teachers, a literature review, and an analysis of the independent curriculum syllabus.

Design

Design Stage is the design of STEM-based e-modules, which includes the module structure, mapping content to STEM components, designing links, and planning activities that enhance problem-solving skills.

Development

The development stage involves creating e-modules using software such as Canva, Flip PDF, and HTML5. Content, technical, and media experts would validate the developed e-modules. They will subsequently be updated using feedback from these experts.

Instruments and Data Collection Techniques

Table 1. Types of Instruments and Data Collection Techniques

No	Measured Aspects	Types of Instruments	Indicators/Assessment Items	Data Collection Techniques	Subject
1	Validity of E-Modules	Expert Validation Sheet	- Content alignment with the curriculum - Conceptual accuracy - Integration of STEM elements - Language and presentation	4-point Likert scale questionnaire	Subject material experts, media experts, technical experts, pedagogic experts
2	The Practicality of E-Modules	Teacher&Student Response Questionnaire	- Ease of use - Suitability of materials - Impact on learning - Efficiency of time and implementation	4-point Likert scale questionnaire	Physics teacher and 11th-grade high school students

Data analysis technique

The validity, reliability, and practicality of the e-module developed were analyzed using a quantitative descriptive method.

1. Instrument Validation and Reliability

Expert ratings were used to establish the instrument's validity, as the experts who assessed it combined the items based on predetermined indicators and provided suggestions for improvement. Experts involved in the study included experts in physics teaching, teaching materials development, and learning assessment (Retnawati, 2016) Cronbach's Alpha was used to determine the reliability of the instrument with the help of the following formula (Forester et al., 2024)

$$r_{11} = \left[\frac{k}{(k-1)}\right]\left[1 - \frac{\sum \sigma\frac{2}{b}}{\sigma\frac{2}{t}}\right]$$

Explanation:

r_{11}= instrument reliability coefficient (total test)

k = number of valid questions

$\sum \sigma\frac{2}{b}$ = number of item variants

$\sigma\frac{2}{t}$ = total score variant

The reliability test instrument considered Cronbach's Alpha, which got the value 0.87 on the instrument of material validity, the value 0.85 on the instrument of media validity, the value 0.86 on the instrument of pedagogical validity, the value 0.84 on the instrument of technical validity, and the value 0.89 on the instrument of practical validity. The total value is greater than the reliability of 0.60, which is indicative of accuracy, and the entire instrument is used in a credible and suitable examination in the educational research study.

2. Validity Analysis

Data acquired on the expert validity sheet were analyzed using a 4-point Likert scale. The following formula obtained the mean on each aspect:

$$\bar{X} = \frac{\sum X}{n}$$

Explanation:

$\bar{X}$ = average score

$\sum X$ = total score of all eligibility values

n = number of items assessed

The resulting average score was categorized as follows (Khasanah & Nurmawati, 2021):

Table 2. Category of Eligibility Value

Score Range Average	Eligibility Category
3.26 – 4.00	Very Valid
2.51 – 3.25	Valid
1.76 – 2.50	Fairly Valid
1.00 – 1.75	Not Valid

3. Practicality Analysis

Practicality data from teachers and students were also analyzed descriptively using the same 4 point Likert scale. The average scores were then classified based on the following categories (Yanuar & Festiyed, 2024).

Table 3. Category of Practicality Value

Score Range Average	Eligibility Category
3.26 – 4.00	Very Practical
2.51 – 3.25	Practical
1.76 – 2.50	Fairly Practical
1.00 – 1.75	Not Practical

RESULTS AND DISCUSSION

Analysis

Physics learning in schools generally still tends to focus on mastering conceptual knowledge alone, without providing sufficient space for students to develop higher-order thinking skills, such as problem-solving. This affects students' low active participation in the learning process and their lack of contextual understanding of the application of physics concepts in everyday life. Students tend to only memorize formulas and procedures without understanding the meaning and function of each step in the solution.

In fact, problem-solving skills are essential for developing 21st-century skills, such as critical thinking, creativity, and logical decision-making. At this stage, the researcher also analyzes the curriculum used in schools to inform product development. Observations are made on curriculum documents and an analysis of learning outcomes within the applicable Learning Objectives Flow (ATP).

Based on the analysis results, sound wave material is chosen as a development topic because it is considered to have great potential for integration with the STEM approach and is related to real problems that are close to students' lives. This analysis is important to ensure that the products developed, both in content and in learning models, remain aligned with the demands and characteristics of the Merdeka curriculum. In addition, the researcher identifies students' characteristics, particularly in problem-solving abilities. Based on the observation results and initial data, most students have difficulty understanding problems, planning solution steps, executing solutions systematically, and evaluating results. Therefore, there is a need for learning media that not only present the material but also train problem-solving skills in a gradual and structured manner.

.

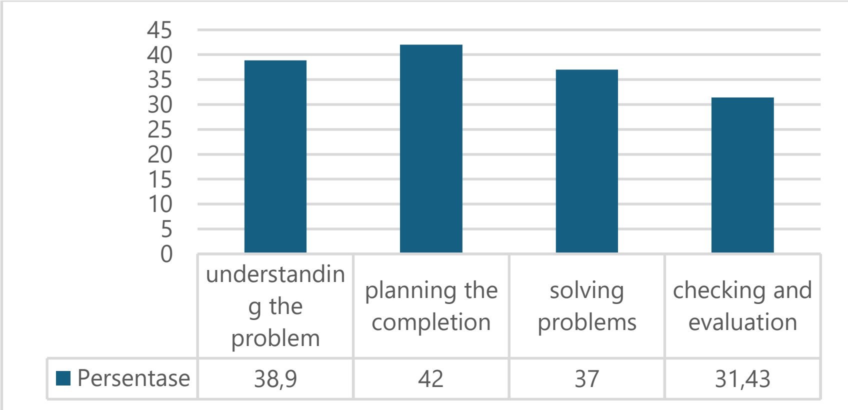

Figure 2. Components of Students' Problem-Solving Skills

Design

During the design phase, the researchers were developing the appearance and structure of STEM-based e-modules, considering pedagogical, content, and visual considerations relevant to the nature of the students. The e-module design features a beautiful cover page with a title and the module's main topic, STEM-Based Physics E-Module: Sound Waves. The module includes appropriate visual illustrations, such as sound waves. The e-module structure is subdivided into a few major segments, viz. introduction, problem spur (contextual), main material, STEM-based activities, exercises, and reflection. The particular focus is on the incorporation of the elements of Science, Technology, Engineering, and Mathematics in the form of simple experiments, observation of real events, and mini projects.

Figure 3. E-Module Cover

The graphic design is also basic but interactive, and the colors are neutral, making it easy to view. Several screenshots were created: an introductory page, an interactive sound simulation, a Doppler effect simulation, and an interface of a multiple-choice interactive quiz. The navigation will be intuitive, ensuring students can easily navigate between pages. Furthermore, each sub-topic will include concept reinforcement and problem-solving activities to promote active student participation. All these factors aim to encourage self-study and continually develop students' critical thinking and problem-solving skills.

Development Validasi E-Modul

Product validation includes four assessment aspects: material validation, media validation, pedagogical validation, and technical validation. The results of the material validation assessment are presented in Table 4.

Table 4. Material Validation Results

Statement	Average
Appropriateness of material to high school learning outcomes	3.67
Accuracy of sound wave concepts in the module	4
Depth and completeness of material content	3.33
Relevance of material to the STEM	3.67
Approach Appropriateness of practice questions to learning objectives	4
Context of material to real life	4

Based on Table 4, the validation of the STEM-based e-module was conducted by three material experts to assess the quality of its content across six indicators. Based on the calculation results, all indicators had average scores above 3.26, indicating they fall into the very valid category. The indicators with the highest scores were 'Alignment of practice questions with learning objectives' and 'Relevance of material to real-life contexts,' with a score of 4.00, indicating that the questions are aligned with learning objectives and contextual to students' lives. Meanwhile, the indicator 'Accuracy of sound wave concepts in the module' also received a high score of 4, reflecting the scientific accuracy of the presented concepts.

The other three indicators, namely 'Alignment of material with high school learning outcomes' (3.67), 'Relevance of material to the STEM approach' (3.67), and 'Depth and completeness of content' (3.33), also fall into the very valid category, although the depth of material indicator had the lowest score. This indicates that the material is already appropriate and aligned with the curriculum, but could still be improved in terms of deeper exploration or additional coverage. Overall, all content aspects of the e-module have been validated with excellent results and are deemed valid for use in STEM-based physics learning, particularly for the topic of sound waves.

Table 5. Media Validation Results

Statement	Average
Visual design (layout, colors, typography)	3.33
Consistency and navigation between pages	4
Media compatibility with digital devices	3
Quality of supporting media (images, videos, graphics)	3.33
Interactivity between content	3

Based on Table 5, the results show an average score ranging from 3.00 to 4.00. The indicator 'Consistency and navigation between pages' received the highest score of 4.00, placing it in the 'very valid' category. This shows that the inter-page layout of the e-module is uniform and user-friendly for students. The other two indicators, Visual design (layout, colors, typography) and Quality of supporting media (images, videos, graphics), each scored 3.33 and were also classified as very valid, indicating that the visuals and multimedia used in the e-module were of good quality overall.

In the meantime, the indicators Media compatibility with digital devices and Interactivity between content have a score of 3.00, which is in the valid category. Despite these scores affirming that the module may be used, there are deficiencies, especially in cross-device presentation, and perceived constraints on the content's interactivity. Thus, the responsiveness and interactive functionality, e.g., automated quizzes, simulations, or active navigation buttons, which may enhance the student learning experience, need to be improved to make the overall rating very valid.

Table 6. Pedagogical Validation Results

Statement	Average
Suitability for high school students' characteristics	3.33
Clarity of learning objectives	3
Learning strategies used in the module	3.33
Encouraging critical thinking and problem-solving skills	3.67
Integration of a holistic STEM approach	3.33

According to Table 6, the evaluation findings indicate that four out of five indicators scored an average of 3.33: Alignment with the characteristics of high school students, Learning strategies used in the module, Holistic integration of the STEM approach, and Clarity of learning objectives. All these refer to the category of very valid, indicating that the module's pedagogical factors have been satisfactorily addressed, from learning planning to designing methods that address the needs of 21st-century students.

At the same time, the indicator with the highest score, promoting critical thinking and problem-solving skills, was rated 3.67, indicating that the e-module is successful in teaching students to think critically and solve problems in their everyday lives. This is one of the most important aspects because problem-solving skills and critical thinking are the major pillars of STEM-based learning. Generally, the pedagogical points of the e-module are considered valid. However, it is recommended to refine the clarity of the objectives and explore learning strategies to make them more explicit and varied.

The technical validation aspect is one of the most crucial components of the e-module validation measure, since it involves the ease of access, functional stability, and performance of the learning media under different device and network requirements. As shown in the validation results graph, five indicators used to evaluate technical validation have been outlined: accessibility, cross-device compatibility, error-free operation, flexible file formats, and system responsiveness. This assessment ensures that not only does the e-module contain rich, well-designed material, but it is also prepared to be used by students in both online and offline settings without causing any serious technical problems. Table 7 shows the technical validation findings.

Table 7. Technical Validation Results

Statement	Average
Ease of access and technical stability	4
Compatibility with various devices (mobile phones, laptops)	3.67
No technical errors (broken links, display errors, etc.)	4
File formats support online and offline learning	4
Module loading speed and responsiveness	3.67

The results of the technical validation show that the e-module is highly valid for learning. Three indicators, including 'Ease of access and technical stability', 'No technical problems (broken links, display problems, etc.)', and File format supports both online and offline learning had a perfect score of 4.00. This indicates that the e-module is very stable, has no technical issues, and is adaptable to both online and offline applications. This is important because a technically sound e-module helps the student learn without requiring access to data or a display to disrupt the learning process.

The other two indicators, which included Compatibility with different devices, loading speed, and module responsiveness, received a score of 3.67, which is still considered valid. The only difference is that the slightly lower scores indicate there may be performance variations among some devices, e.g., loading time or display sharpness. Altogether, the technical features of this e-module are designed to an outstanding standard and offer a smooth, responsive, user-friendly learning process from a technological perspective. This certainly provides evidence of why digital-based learning in high schools is successful.

Practicality Test

The practicability of the STEM-based e-module was assessed using a practicability test involving three physics teachers. The selection of teachers was based on their strategic position as the main users in the classroom learning process. The measured criteria were ease of use, relevance of the material used, how it affected the learning process, and how much time it saved on implementation. This evaluation provides a picture of the effective use of the developed e-module within the physics instructional framework, along with the prospects it brings for teaching efficiency and quality within schools. Table 8 displays the findings of the teacher practicality assessment.

Table 8. Practicality Test Results for Teachers

Aspect	Item	Average
Ease of use	3	3.67
Material suitability	3	3.56
Impact on learning	3	3.67
Time efficiency of implementation	2	3.50

The results of the practicality test indicate that ease of use scored an average of 3.67, with a description of "very practical," meaning that the e-module is easy to use for teachers, both in its technical aspects and in leveraging the media of learning facilities. On the material relevance aspect, they received an average score of 3.56, which also falls under the very valid category, and thus it can be concluded that the content of the e-module is relevant to learning objectives, needs of the students, and enhances the use of different learning media (LKPD) as well as videos. This further strengthens the e-module's content, which aligns with the curriculum and learning requirements.

Secondly, in terms of the effect on learning, teachers rated it 3.67 on average, which is considered very practical. It means that the e-module will help teachers provide material, and learners will be better able to learn in the process. In the meantime, regarding time efficiency and implementation, the average score was 3.50, as well, in the very practical category, indicating that the e-module will be easily adaptable to online and offline learning and will also fit the allocated time frame. In general, the e-module has been very practical according to teacher analysis.

A practicality test was also provided to students to determine how convenient the developed STEM-based e-module is to work with, how well it meets the learning needs, and influences the learning process in a positive manner. The assessed factors were ease of use, participation in the learning process, content readability, and intervention in learning effectiveness. Such evaluation is important to ensure that the e-module passed not only the test of material and technical issues but was also practical when applied by students in physics teaching and learning exercises. Table 9 shows the findings of the student practicality assessment.

Table 9. Practicality Test Results for Students

Aspect	Item	Average
Ease of use	4	3.75
Material suitability	3	3.73
Impact on learning	3	3.73
Time efficiency of implementation	3	3.53

The results revealed that the usability dimension received a mean score of 3.75, which can be considered an efficient classification. Learners encountered no problems accessing and using all digital learning resources, including the E-Module, student worksheets (LKPD), and instructional videos. Moreover, the learner's participation in the learning process remained very high, with an average of 3.73, indicating that this e-module was effective in enhancing participation in both self-directed learning and group discussions. This proves that the e-module has been developed with features and methodologies that align with the needs and attributes of modern learners.

In terms of content transparency and appropriateness, the learners scored an average of 3.73, confirming that the instructional materials were structured functionally, had good context, and were understandable. In the meantime, the impact on instruction effectiveness was rated at 3.53, reflecting learners' impressions that they gained better knowledge of sound-wave concepts and the effectiveness of electronic learning. Overall, all practicality measures used by the learners fell within the highly practical category, confirming the e-module's preparedness for widespread use in teaching physics, especially in STEM at the senior high school level.

The overall evaluation of its practicality in the STEM-based e-module confirmed the module's designation as highly practical. Based on the assessment of three teachers, all the dimensions, including usability (mean 3.83), material appropriateness (3.83), learning influence (3.67), and temporal efficiency (3.5), outperformed the trend score of 3.26. These results were further supported by learner feedback, which averaged more than 3.5 across usability, transparency, and involvement. This highlights the user-friendliness of the e-module, its efficiency in aiding the learning process, and the flexibility of both the virtual and face-to-face learning environments.

Discussion

The results of the current research indicate that the given e-module on sound waves has good validity and usability, making it suitable for implementation in the teaching of physics in senior high schools. These results provide support for the claim that the e-module aligns with the features of effective educational tools, in particular those that emphasize the interface's exciting design, the accuracy of the conceptual material, and the instructional value's meaning.

In comparison with prior studies, the findings can be related to (Herawati & Muhtadi, 2018), results that highlighted how interactive digital learning can be used to enhance the motivation and learning of the concepts by the visual and auditory features. Similarly, (Hamid & Alberida, 2021) In a study, other researchers found that incorporating STEM concepts into electronic learning content helps connect theoretical physics concepts to real-world settings, thereby reinforcing students' understanding. In addition to this, (Asrizal et al., 2023) studies have indicated the importance of including STEM models in modules that enhance critical literacy and reasoning skills, as they encourage learners to analyze, create, and evaluate scientific phenomena.

The same investigation also supports the findings of (Dywan & Airlanda, 2020), research has shown that STEM learning, which is based on projects, significantly improves the critical thinking and problem-solving skills in learners. Furthermore, (Rasyid & Wiyatmo, 2024) Also, reviewed articles indicated that developed digital modules based on the ADDIE framework are not only valid and applicable but also flexible to implement in both virtual and traditional learning classroom environments, ensuring flexibility in presentation. These results are strongly aligned across studies, suggesting that the e-text of STEM created in this paper can bridge the gap between theory and practice in using problem-solving skills to meet the objectives of the Merdeka Curriculum in imparting students with critical, innovative, and reflective thinking skills.

In practical terms, the e-module is effective, as it provides concrete benefits to both teachers and students. For instructors, the resource is a versatile online tool that delivers complex physics concepts through situational and discovery-based learning. It enables teachers to develop practical projects and experimental tasks that help them correlate abstract concepts with real-life phenomena, such as the reflection of sound waves, resonance, and changes in the frequency of moving objects. The module serves as a stimulus and self-directed learning tool that provides learners with curiosity, practical experimentation, and the practical application of scientific principles through STEM-oriented tasks. This method not only leads to content understanding but also to the development of scientific reasoning and analytical problem-solving skills that are critical in the modern learning environment.

Although these are the positive features, this study has limitations that are necessary to mention. It was a limited study, limited to the validation and usability testing phases, without an effectiveness test in real classroom settings. Consequently, the effect of e-module on measurable educational effects, e.g., academic performance or long-term memory, has not yet been investigated. In addition, the usability test sample, which involves a small group of educators and learners, may limit the generalizability of the results. Finally, the research focused solely on the content of sound waves, and the opportunities to apply this resource to other areas of physics remained unexplored, awaiting future efforts.

Future research must therefore use experimental or comparative research designs to determine the effectiveness of this STEM-oriented e-module in enhancing conceptual mastery and analytical reasoning skills across different topics in physics. The integration of digital tracing technologies and customized learning features might also yield greater insight into learner engagement patterns and academic accomplishments.

CONCLUSION

Based on the findings of the research and development process, it can be stated that the STEM-oriented physics e-module, which covers the concepts of sound waves among senior high school learners, has high validity and usability as a learning tool. The results of the expert review, conducted by experts in content, design, and educational methodologies, demonstrate that the e-module meets the criteria for subject matter accuracy, visual presentation quality, and instructional and technical soundness. The usability test, collected using teacher and student feedback tools, also shows positive results in ease of use, understanding of the material, and the suitability of the e-module for the features of physics teaching. This implies that the developed e-module can be used as supplementary instructional material in the study of physics and aligns with the specifications of the Merdeka Curriculum framework. In a real-life situation, an educator can use this e-module as an auxiliary teaching aid in a discovery-based or task-based mode of learning to help a learner acquire an understanding of theoretical physics concepts through real-world association. Teachers are advised to introduce the learning tasks incorporated in the e-module as classroom discussions or group work on real-life acoustic phenomena, e.g., how to address noise pollution in the environment, structural vibration in buildings, or general sound-related research and investigations. To carry out future research, the recommendation is to adopt efficacy tests to comprehensively determine the impact of e-module implementation on learners' academic performance and analytical thinking. However, future researchers can also develop interactive activities or integrate a learning data tracking process to increase learner engagement and create responsive STEM e-modules that adapt the learning process to the level and competencies of the respective students.

ACKNOWLEDGMENTS

Thank you to Universitas Islam Madura, especially the Physics Education department.

REFERENCES

Arifin, F. A., Mufit, F., & Asrizal. (2021). Validity and practicality of interactive multimedia based on cognitive conflict integrated new literacy on thermodynamic and mechanical waves material for class xi high school students. *Journal of Physics: Conference Series*, *1876*(1). https://doi.org/10.1088/1742-6596/1876/1/012052

Aripin, W. A., Sahidu, H., & Makhrus, M. (2021). Efektivitas Perangkat Pembelajaran Fisika Berbasis Model Problem Based Learning untuk Meningkatkan Kemampuan Pemecahan Masalah dan Kemampuan Berpikir Kritis Peserta Didik. *Jurnal Penelitian Dan Pembelajaran Fisika Indonesia*, *3*(1). https://doi.org/10.29303/jppfi.v3i1.120

Asmiyunda, A., Guspatni, G., & Azra, F. (2018). Pengembangan E-Modul Kesetimbangan Kimia Berbasis Pendekatan Saintifik untuk Kelas XI SMA/ MA. *Jurnal Eksakta Pendidikan (Jep)*, *2*(2), 155. https://doi.org/10.24036/jep/vol2-iss2/202

Asrizal, A., Dier, M., Mardian, V., & Festiyed, F. (2023). STEM integrated electronic student worksheet to promote conceptual understanding and literacy skills of students. *Journal of Physics: Conference Series*, *2582*(1). https://doi.org/10.1088/1742-6596/2582/1/012052

Darojat, D. J., & Zakirman, Z. (2024). Inovasi Pembelajaran Fluida Dinamis dengan Discovery Learning dan Alat Peraga: Dampak pada Kreativitas dan Pemahaman Siswa. *Wacana Akademika: Majalah Ilmiah Kependidikan*, *8(2)*, 356–367.

Dywan, A. A., & Airlanda, G. S. (2020). Efektivitas Model Pembelajaran Project Based Learning Berbasis STEM dan Tidak Berbasis STEM Terhadap Keterampilan Berfikir Kritis Siswa. *Indiktika : Jurnal Inovasi Pendidikan Matematika*, *4*(2), 344–354. https://doi.org/https://doi.org/10.31004/basicedu.v4i2.353

Fauziah, A. D., Susila, A. B., & ... (2022). Pengembangan E-Modul Fisika Berbasis Android Dengan Pendekatan Stem Pada Materi Fluida Dinamis. *Prosiding Seminar …*, *November*, 164–167. https://journal.ikippgriptk.ac.id/index.php/snpp/article/view/5124%0Ahttps://journal.ikippgriptk.ac.id/index.php/snpp/article/viewFile/5124/2095

Firmansyah, F., Sukarno, S., Kafrita, N., & Al Farisi, S. (2022). Pengaruh Model Problem Based Learning (Pbl) Terhadap Kemampuan Pemecahan Masalah Fisika Siswa Sma. *Physics and Science Education Journal (PSEJ)*, *2*, 75–82. https://doi.org/10.30631/psej.v2i2.1447

Forester, B. J., Idris, A., Khater, A., Afgani, M. W., Isnaini, M., Islam, U., Raden, N., & Palembang, F. (2024). Penelitian Kuantitatif : Uji Reliabilitas Quantitative Research : Data Reliability Test. *Jurnal Pendidikan, Ilmu Sosial, Dan Pengabdian Kepada Masyarakat*, *4*(3), 1812–1820. https://jurnal.permapendis-sumut.org/index.php/edusociety

Hamid, A., & Alberida, H. (2021). Pentingnya Mengembangkan E-Modul Interaktif Berbasis Flipbook di Sekolah Menengah Atas. *Edukatif : Jurnal Ilmu Pendidikan*, *3*(3), 911–918. https://doi.org/10.31004/edukatif.v3i3.452

Herawati, N. S., & Muhtadi, A. (2018). Pengembangan modul elektronik (e-modul) interaktif pada mata pelajaran Kimia kelas XI SMA [Development of interactive electronic modules (e-modules) in Chemistry subjects for grade XI high school.]. *Jurnal Inovasi Teknologi Pendidikan*, *5*(2), 180–191.

Hibatullah, H., Rahardjo, D. T., & Haryani, F. (2024). Peningkatan Pemahaman dan Kerjasama Siswa Menggunakan Model Pembelajaran REACT Pada Materi Kalor. *Jurnal Riset Dan Inovasi Pembelajaran*, *4*(2), 1458–1470. https://doi.org/10.51574/jrip.v4i2.1850

Ibrahim, R. (2011). *Model Pengembangan ADDIE*. Jaya Publishing.

Kemendikbudristek. (2021). *Transformasi Pembelajaran Melalui Kurikulum Merdeka*. Direktorat Jenderal PAUD, Dikdas, dan Dikmen.

Kemendikbudristek. (2022). Panduan Pembelajaran dan Asesmen. *Badan Standar, Kurikulum, Dan Asesmen Pendidikan Kementerian Pendidikan, Kebudayaan, Riset, Dan Teknologi Republik Indonesia*, 123.

Khasanah, I., & Nurmawati, I. (2021). Pengembangan Modul Digital sebagai Bahan Ajar Biologi untuk Siswa Kelas XI IPA. *Indonesian Journal of Mathematics and Natural Science Education*, *2*(1), 34–44. https://doi.org/10.35719/mass.v2i1.57

Kiswanda, V., Aswirna, P., & Nurhasnah. (2021). Pengembangan E-Modul Fisika Berbasis Stem Dengan Prinsip Pembangunan Berkelanjutan Terhadap Literasi Sains Siswa Kelas Xi. *Journal Cerdas Mahasiswa*, 62–75.

Lismawati, Salamang Salmiah Sari, & Sidin Ali. (2024). Penerapan Model Pembelajaran Discovery Learning Dalam Meningkatkan Minat Belajar Fisika Kelas Xi Sman 8 Jeneponto. *Jurnal Sains Dan Pendidikan Fisika*, *20*(3), 238–248. https://doi.org/10.35580/jspf.v20i3.5294

Mahombar, A. (2024). Analisis Pemahaman Konsep dan Kendala Pemahaman Konsep Materi Getaran dan Gelombang. *Fisika Dan Pembelajarannya*, *6*(2), 74–79. https://doi.org/10.31605/phy.v6i2.3683

Nasir, M., & Fakhruddin, Z. (2023). Design and Analysis of Multimedia Mobile Learning Based on Augmented Reality to Improve Achievement in Physics Learning. *International Journal of Information and Education Technology*, *13*(6), 993–1000. https://doi.org/10.18178/ijiet.2023.13.6.1897

Padwa, T. R., & Erdi, P. N. (2021). Penggunaan E-Modul Dengan Sistem Project Based Learning. *JAVIT : Jurnal Vokasi Informatika*, 21–25. https://doi.org/10.24036/javit.v1i1.13

Purnama, S. (2021). *Pengembangan E-Modul Menggunakan Pendekatan STEM untuk Meningkatkan Kemampuan Pemecahan Masalah Peserta Didik pada Materi Gelombang Bunyi* [UIN Sunan Gunung Djati Bandung]. https://digilib.uinsgd.ac.id/id/eprint/38398

Rana, D. A., Fitrian, A., & Dasmo, D. (2023). … E-Modul Fisika Berbasis STEM (Science, Technology, Engineering, And Mathematics) Menggunakan Aplikasi Flipbuilder Pada Materi Alat Optik SMA Kelas XI. *SINASIS (Seminar …*, *4*(1), 83–91. https://proceeding.unindra.ac.id/index.php/sinasis/article/view/7115%0Ahttps://proceeding.unindra.ac.id/index.php/sinasis/article/viewFile/7115/2466

Rasyid, A., & Wiyatmo, Y. (2024). Pengembangan E-Modul Fisika Berbasis Pbl Berbantuan Aplikasi Canva Untuk Meningkatkan Keterampilan Berpikir Kritis Dan Kemandirian Belajar Peserta Didik Sma. *Jurnal Pendidikan Fisika*, *11*(1), 36–55. https://doi.org/10.21831/jpf.v11i1.20787

Retnawati, H. (2016). *Analisis Kuantitatif Instrumen Penelitian*. Parama Publishing.

Riwanto, D., Azis, A., & Arafah, K. (2019). Analisis Pemahaman Konsep Peserta Didik Dalam Menyelesaikan Soal-Soal Fisika Kelas X Mia Sma Negeri 3 Soppeng. *Jurnal Sains Dan Pendidikan Fisika*, *15*(2), 23–31. https://doi.org/10.35580/jspf.v15i2.11033

Rizkita, N. I., & Mufit, F. (2022). Analisis Pemahaman Konsep dan Sikap Siswa Terhadap Belajar Fisika Pada Materi Hukum Newton Tentang Gerak. *Jurnal Eksakta Pendidikan (Jep)*, *6*(2), 233–242. https://doi.org/10.24036/jep/vol6-iss2/599

Roslina, Herpratiwi, & Firdaus, R. (2025). Multimedia Interaktif Berbasis Problem Based Learning untuk Meningkatkan Pemahaman Konsep Siswa Pada Mata Pelajaran Fisika. *Educate: Jurnal Teknologi Pendidikan*, *10*(1), 41–54. https://doi.org/10.32832/educate.v10i1.18342

Safitri, M., & Aziz, M. R. (2022). ADDIE, sebuah model untuk pengembangan multimedia learning. *Jurnal Pendidikan Dasar*, *3*(2), 50–58. http://jurnal.umpwr.ac.id/index.php/jpd/article/view/2237

Saputra, I. G. P. E. (2024). Efektivitas Discovery Learning Terintegrasi Kearifan Lokal terhadap Pemahaman Konsep Fisika di Era Kurikulum Merdeka. *Jurnal Pendidikan Fisika UNDIKSHA*, *14*(1), 469–479.

Simbolon, J., Sakti, I., Wardana, R. W., Sutarno, S., & Nursaadah, E. (2023). Pengembangan E-Modul Berbasis Stem Pada Materi Suhu Dan Perubahannya Untuk Siswa Kelas Vii Smp. *DIKSAINS : Jurnal Ilmiah Pendidikan Sains*, *3*(2), 108–117. https://doi.org/10.33369/diksains.3.2.108-117

Sitinjak, E. K. (2022). Penggunaan Video Pembelajaran untuk Meningkatkan Kemampuan Pemecahan Masalah Fisika. *Jurnal Penelitian Dan Pengembangan Pendidikan*, *6*(1), 19–25. https://doi.org/10.23887/jppp.v6i1.45006

Susanti, D., Fauziah, A. D., & Susila, A. B. (2023). E-Modules of dynamic fluid using Science, Technology, Engineering and Mathematics (STEM) approach android applications. *Journal of Physics: Conference Series*, *2596*(1). https://doi.org/10.1088/1742-6596/2596/1/012082

Syarah Syahiddah, D., Dwi Aristya Putra, P., & Supriadi, B. (2021). Pengembangan E-Modul Fisika Berbasis STEM (Science, Technology, Engineering, and Mathematics) pada Materi Bunyi di SMA/MA. *Jurnal Literasi Pendidikan Fisika (JLPF)*, *2*(1), 1–8. https://doi.org/10.30872/jlpf.v2i1.438

Szabo, Z. K., Körtesi, P., Guncaga, J., Szabo, D., & Neag, R. (2020). Examples of problem-solving strategies in mathematics education supporting the sustainability of 21st-century skills. *Sustainability (Switzerland)*, *12*(23), 1–28. https://doi.org/10.3390/su122310113

Wahyuni, N. P. (2021). Penerapan Pembelajaran Berbasis STEM untuk Meningkatkan Hasil Belajar IPA. *Journal of Education Action Research*, *5*(1 SE-Artikel), 109–117. https://doi.org/10.23887/jear.v5i1.31554

Yanuar, D., & Festiyed, F. (2024). the Validity of Authentic Assessment Instruments in the Poe of Dynamic Fluid Materials for High School. *EduFisika: Jurnal Pendidikan Fisika*, *9*(1), 01–13. https://doi.org/10.59052/edufisika.v9i1.31638

Yulianti, E. (2018). *Analisis pemahaman konsep dan pemecahan masalah biologi berdasarkan kemampuan berpikir kritis peserta didik kelas XI SMA Al-Azhar 3 Bandar Lampung* [Doctoral dissertation, UIN Raden Intan Lampung]. https://repository.radenintan.ac.id/id/eprint/2905

Yunita, S. (2024). *Pengembangan E-Modul Interaktif Dengan Pendekatan Stem Menggunakan Aplikasi Canva Untuk Meningkatkan Kemampuan Berpikir Kritis Peserta Didik Pada Pembelajaran Fisika* [Doctoral Dissertation, Uin Raden Intan Lampung]. https://repository.radenintan.ac.id/id/eprint/32260

Zulaiha, F., & Kusuma, D. (2020). Pengembangan Modul Berbasis STEM untuk Siswa SMP. *Jurnal Pendidikan Fisika Dan Teknologi*, *6*(2), 246–255. https://doi.org/10.29303/jpft.v6i2.2182