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Sound Wave Teaching Module Using STEM-PBL to Improve Students' Critical Thinking Skills

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Abstract

The lack of teaching modules designed to develop critical thinking skills has become a major obstacle to improving education quality in Indonesia. This study aims to produce a sound wave teaching module using the STEM-PBL approach, which will be assessed in terms of its validity and practicality. This development study uses the ADDIE model involving 32 eleventh-grade students of class XI 2 at SMAN 4 Banjarmasin as trial subjects. Data were collected through teaching module validation sheets and module implementation observation sheets. Data were analyzed both qualitatively and quantitatively in a descriptive manner. Quantitative data were analyzed using average scores and then described qualitatively based on established categorization criteria. Expert and practitioner validation yielded average validity and reliability scores of 3.69 and 0.98, categorized as very valid and highly reliable. Additionally, observations of module implementation classified it as very practical. Therefore, the developed STEM-PBL module is considered feasible for physics learning.

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INTRODUCTION

In the era of the Industrial Revolution 4.0, educational institutions are faced with the challenge of adjusting curricula to produce graduates who not only master knowledge but also possess 21st-century skills relevant to the job market (Illene et al., 2023; Mardhiyah et al., 2021; Qamariah et al., 2021; Sholihah & Lastariwati, 2020). Critical thinking skills involve evaluating various aspects of a problem, weighing all possibilities, and making decisions based on logical considerations (Jamaludin et al., 2022; Komariyah et al., 2018; Mahfudz & Sukarno, 2023; Rahmaniar et al., 2022; Setiadi & Elmawati, 2019; Sumarni & Kadarwati, 2020; Suratmi & Sopandi, 2022; Toheri et al., 2020). Critical thinking is a strong foundation for students to face the challenges and opportunities of the future (Affilia et al., 2023; Anggraeni et al., 2022; Hidayah et al., 2017; Kurniawati et al., 2020; Lim et al., 2023; Romadhon, 2019; Umam & Susandi, 2022). These skills can be sharpened through learning processes at school

Learning is an interactive process aimed at facilitating students in constructing new knowledge and skills (Junaedi, 2019). Senior High Schools (SMA) play a strategic role in developing student potential. At this stage, students are in an active cognitive development phase and are highly curious. Physics is a theoretical subject and a science applied in real life. Through applying physics concepts, students are trained to think critically and solve problems (Harefa, 2019; Harefa, 2022; Hidayah et al., 2017).

Learning Outcomes (LOs) for SMA students entering phase F require them to understand physics concepts and employ scientific approaches involving observation,

investigation, analysis, and logical communication of information. This aligns with several critical thinking indicators, such as analyzing data and information, evaluating arguments or scientific statements, linking concepts to real-life phenomena, and making evidence-based decisions.

Findings by Baktiarso et al. (2023) show that students' critical thinking skills are still categorized as low in physics learning. Factors contributing to the lack of critical thinking skills in schools include students' inability to relate calculation results to real-world phenomena. Another factor is that the teacher-centered approach still dominates classroom instruction (Diva & Purwaningrum, 2023; Khadzir & Sumarmi, 2020). Previous studies have also shown that students' critical thinking abilities in physics learning remain low. This is partly due to students' difficulty connecting calculations with everyday phenomena and the continued use of teacher-centered teaching methods. However, to date, few studies have specifically developed physics teaching modules—especially on sound waves—using a STEM approach integrated with the Problem-Based Learning (PBL) model. Yet, the topic of sound waves is highly relevant for connecting with real-life situations that are familiar to students. Therefore, developing a STEM-PBL-based teaching module is important to build critical thinking skills through meaningful, contextual, and problem-solving-based learning experiences. A similar issue was also found at one of the public high schools in Banjarmasin, namely SMAN 4 Banjarmasin. A preliminary study involving 32 students in class XI 2 revealed an average critical thinking score of 9.77, categorized as very low. These results indicate that the current teaching modules are ineffective in developing students' critical thinking skills. This highlights the need for innovation in teaching module design.

Physics learning becomes more effective when it adopts approaches emphasizing independent discovery and investigation rather than passive lecture delivery (Handayani, 2016). The Problem-Based Learning (PBL) model can be an appropriate choice. PBL is a learning model that positions students as active problem-solvers, where they learn by seeking solutions to real-world problems (Adawiah et al., 2024; Lismaya, 2019; Nisa et al., 2022; Nugroho & Hermasari, 2023). The main goal of PBL is to equip students with comprehensive cognitive abilities, especially in critical thinking and effective problem solving, and to encourage students to become independent learners who are confident in facing real-world challenges (Arends, 2012). Effective implementation of PBL can sharpen students' critical thinking skills in complex situations while also fostering the development of essential social skills, such as teamwork and interpersonal communication (Dakabesi & Luoise, 2019; Heriyanti, 2022; Rohmatin et al., 2022). During the group investigation and project development stages in PBL, concepts from Science, Technology, Engineering, and Mathematics (STEM) are integrated. The STEM approach allows students to apply knowledge from various disciplines in an integrated manner to solve real-world problems (Arianti et al., 2022; Putri et al., 2020; Putri & Dwikoranto, 2022; Razali et al., 2022; Suyidno et al., 2024). These four aspects of STEM are aligned with real-world problems addressed in PBL, making the two approaches highly compatible (Selisne et al., 2019).

The STEM approach in PBL encourages students to think critically and creatively in analyzing problems from multiple perspectives, enabling them to design innovative and comprehensive solutions in real-life contexts (Nurazmi & Bancong, 2021; Syukri, 2020; Yasifa et al., 2023). The implementation of STEM-PBL has been proven effective in improving students' critical thinking skills (Arifah et al., 2023; Ariyatun & Octavianelis, 2020; Mulya et al., 2023; Nurazmi & Bancong, 2021; Windari & Yanti, 2021).

The developed STEM-PBL-based teaching module has integrative, contextual characteristics and is oriented toward 21st-century skill development. The module combines science, technology, engineering, and mathematics in a unified learning

experience, starting from real-world problems and culminating in creating applicable projects. Learning activities are designed to encourage students to think critically, solve problems, and collaborate effectively. Moreover, the module places students as active participants in learning through exploratory activities, experiments, discussions, and reflections on phenomena relevant to their everyday lives.

METHODS

This research is a development study to produce a STEM-PBL-based sound wave teaching module to improve students' critical thinking skills. The study involved 32 students from class XI 2 of a public high school in Banjarmasin City as the trial subjects. It examined the feasibility of the STEM-PBL teaching module in enhancing students' critical thinking skills using the ADDIE development model, as illustrated in Figure 1.

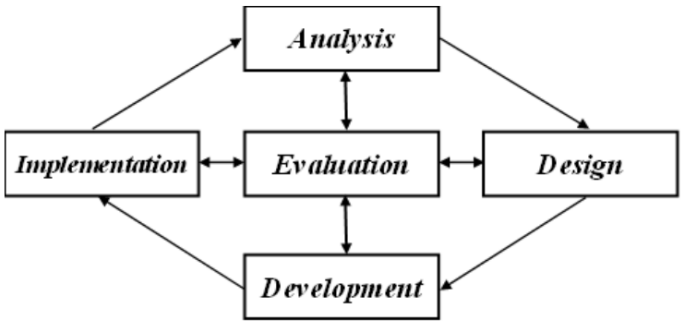

Figure 1 The ADDIE development model (Adapted from Tegeh et al., 2015)

In the first stage, Analysis, the following aspects were identified: (a) Students' learning needs, where learners—according to their cognitive development stage—require student-centered learning processes, and (b) Characteristics of the sound wave material, which is contextual and applicative, containing abstract and quantitative concepts, making it highly suitable for STEM and PBL approaches.

The second stage, Design, involved designing the STEM-PBL-based teaching module, which included developing the learning activity flow, selecting media, and designing evaluation instruments. The third stage, Development, involved producing the teaching module based on the previous design. It was then reviewed and revised with the involvement of experts to ensure the quality of its appearance and the integration of the STEM-PBL approach. The fourth stage, Implementation, consisted of applying the teaching module in the classroom to observe the learning process and how students interacted with the developed module. The final stage, Evaluation, assessed the feasibility of the module based on its validity and implementation results.

Data collection techniques for the developed teaching module included validation and implementation observation sheets. Two academic experts and one practitioner validated the teaching module. A module is considered valid if it scores between $2.80 < r \leq 3.40$. Meanwhile, the implementation sheet was used by three observers to assess the practicality of the module. A module is considered practical if it scores between $60 < X \leq 80$.

RESULTS AND DISCUSSION

This study aimed to develop a STEM-PBL-based sound wave module to enhance students' critical thinking skills. The results of the development are shown in Figure 2. The module was developed based on the learning competency standards of the Merdeka Curriculum, ensuring it meets the learning needs of eleventh-grade high school students.

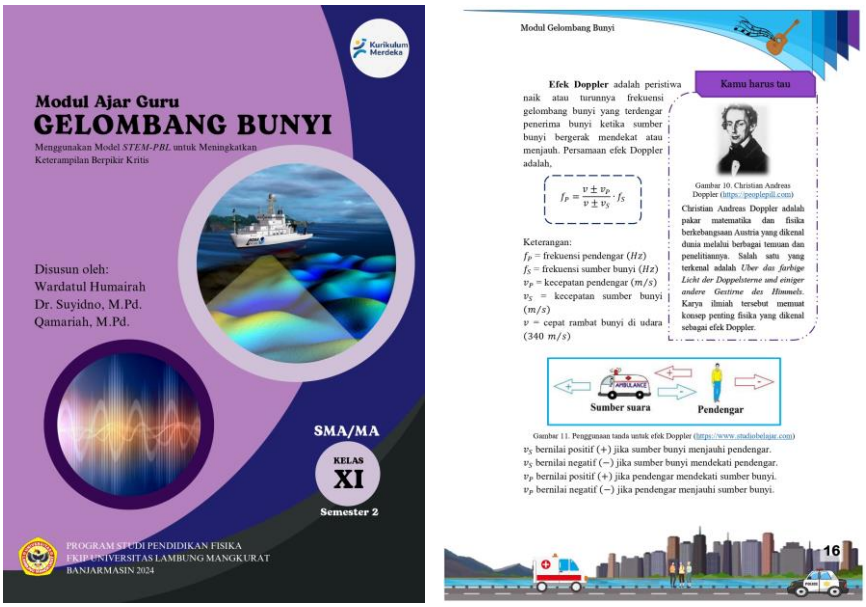

Figure 2 Display of the teaching module design

The teaching module consists of the cover, general information, core components, a detailed schedule of meetings, and appendices. Three experts validated the developed module. A module is considered valid if its validity score falls within the "valid" category. Table 1 shows the module's validity and reliability scores, which were reviewed across cover design, general information, core components, meeting schedule details, and appendices.

Table 1. Validity and reliability scores of the teaching module

Assessment Aspect	Average	Category
Module cover design	3.83	Very valid
General information	3.71	Very valid
Core components	3.58	Very valid
Schedule of meetings	3.73	Very valid
Teaching materials	3.60	Very valid
Worksheets	3.67	Very valid
Validity	3.69	Very valid
Reliability	0.98	Very high

The developed teaching module was validated by three experts and declared very valid and reliable. Based on their feedback, revisions were made, and the module is now ready for classroom use. The module cover design was rated very valid. The cover includes visuals that reflect the module content, appropriate font type and size, and high contrast between text and background. The design also includes the author's name, the Merdeka Curriculum logo, and illustrations related to the subject matter (Anggrayni et al., 2023; Camelia et al., 2023).

The general information aspect received a very valid rating. In accordance with the Merdeka Curriculum, the module clearly outlines the module identity, target competencies, and appropriate learning models to support the development of the Pancasila Student Profile. The core components were also rated very valid. These include a systematic structure with clear learning objectives, guiding questions, learning activities, assessment

mechanisms, enrichment, and remedial strategies to ensure deep and meaningful concept comprehension. The appendices were rated very valid and include teaching materials, worksheets, critical thinking tests, and assessment rubrics.

The module's sound wave material covers the basics of sound as a longitudinal mechanical wave that requires a medium to travel. Students are guided to understand various sound characteristics, such as frequency, wavelength, propagation speed, and amplitude. All content is presented contextually, linking concepts to real-life phenomena familiar to students. Each topic is developed through project-based and problem-solving activities in line with the STEM-PBL approach, encouraging observation, analysis, calculation, and critical conclusion drawing.

The validated module was then tested in class XI 2 at SMAN 4 Banjarmasin. Three observers observed the implementation of learning activities to measure its practicality. The results are shown in Table 2.

Table 2 Teaching module implementation scores

STEM-PBL	Meeting 1		Meeting 2		Meeting 3		Meeting 4	
Phase	**Score**	**Category**	**Score**	**Category**	**Score**	**Category**	**Score**	**Category**
Phase 1: Orienting students to the problem	88.33	Very practical	88.33	Very practical	83.33	Very practical	81.67	Very practical
Phase 2: Organizing students to learn	80.56	Very practical	83.33	Very practical	83.33	Very practical	79.17	Practical
Phase 3: Assisting investigation (indiv./group)	80.56	Very practical	86.11	Very practical	75.00	Practical	-	-
Phase 4: Developing and presenting work	-	-	-	-	91.67	Very practical	66.67	Practical
Phase 5: Analyzing and evaluating solutions	70.83	Practical	81.25	Very practical	75.00	Practical	83.33	Very practical
Reliability (PA)	94.89	Reliable	93.67	Reliable	90.08	Reliable	92.55	Reliable

From Tables 1 and 2, we can conclude that the module's reliability is very high. This suggests that (a) the assessments by validators were consistent, (b) the validation instruments were structured and clear, (c) the content matched the students' needs and characteristics, and (d) Instructional design principles were applied correctly.

Based on Table 2, each phase received scores categorized as either practical or very practical across all sessions, indicating that the learning process was implemented in accordance with the session plans outlined in the teaching module. Overall, the module's implementation was categorized as very practical, and the reliability was rated as reliable. Phase 1: The teacher prepared students for learning by greeting them, checking attendance, initiating a prayer, reviewing prior lessons to activate prior knowledge, providing motivation by showing a STEM video, communicating the learning objectives, and explaining the lesson process.

Phase 2: The teacher checks students' understanding of the material through a Q&A session, during which the key points are discussed. This questioning method enhanced student learning outcomes by fostering active interaction between the teacher and students (Ahmad et al., 2017). Then, students were divided into small groups to work on the prepared worksheets. Phase 3: The teacher guided students through scientific inquiry by formulating hypotheses, identifying variables, designing data tables, conducting experiments, recording observations, analyzing the data, and drawing conclusions. The main objective of this phase was to encourage students to actively seek relevant information, allowing them to develop a comprehensive understanding of the problems being investigated. Phase 4: The teacher supported students in planning and preparing a product or project based on the previously defined problem topic. Students created an e-poster, which was later presented in class during the fourth session. Each group took turns presenting while the rest of the class observed and provided feedback. Phase 5: The teacher facilitated students in evaluating and reflecting on the learning process. Students were assessed by completing reinforcement exercises in the worksheets, and the learning session was closed formally.

The developed sound wave learning module offers an innovative approach by integrating STEM and PBL, aligned with the Merdeka Curriculum. The rationale behind developing this module was to harmonize learning practices with curriculum developments and students' evolving needs, particularly within senior high school physics.

PBL encourages students to solve authentic, real-world problems, thus fostering the development of critical thinking skills (Nisa et al., 2022; Pamungkas et al., 2019; Rahayu et al., 2019). Meanwhile, the STEM approach is highly relevant for preparing students to face 21st-century challenges (Dewi & Jauhariyah, 2021; Fitriansyah et al., 2021; Lesmono et al., 2021). In the context of the PBL model, STEM helps students connect across four disciplines by focusing on real-life problems and enhancing critical thinking through interdisciplinary learning.

STEM-PBL has proven effective in enhancing students' conceptual understanding and critical thinking skills (Mardiyanti, 2020; Rahmaniar et al., 2022; Rohmah et al., 2021; Zulfawati et al., 2022). Moreover, STEM-PBL supports students in identifying the best solutions to real-world challenges. The primary goal of this learning strategy is to solve real-life problems through product design and engineering using STEM principles (Hidayah et al., 2024; Suyidno et al., 2021).

CONCLUSION

This study successfully produced a STEM-PBL-based sound wave teaching module that is both valid and practical. The module achieved an average validity score of 3.69, categorized as very valid, and a reliability score of 0.98, indicating a high level of reliability. The module's implementation in classroom settings across multiple meetings consistently received very high scores, confirming its practicality and relevance in enhancing students' critical thinking skills.

CONFLICT OF INTEREST

The authors declare that no conflicts of interest are associated with this research or article.

AUTHORS CONTRIBUTION

In this study, the first author (WH) designed the research, collected the data, drafted the initial manuscript, and analyzed the data. The second author (SS) reviewed the methodology, literature, data collection techniques, and analysis. The third author (QQ)

edited and finally reviewed the article. All authors have read and approved the final manuscript.

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