

Development of E-Modules Integrate with PBL (Problem Base Learning) in High School Physics Subject Class XI

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Received: April 26, 2025

Revised: May 09, 2025

Accepted: June 25, 2025

Published: June 30, 2025

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DOI: [10.29303/jppipa.v11i6.11627](https://doi.org/10.29303/jppipa.v11i6.11627)

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Abstract: This study aims to test the feasibility, practicality and effectiveness of the development of e-modules based on Problem Based Learning (PBL) on sound wave material in Physics class XI at SMA Pertiwi 1 Padang. The method used in this research is Research and Development (R&D) with the 4D model (Define, Design, Develop, Disseminate). The sample used in this study was class XI students at SMA Pertiwi 1 Padang totaling 33 students. The instrument used in the study was a questionnaire sheet for validation of feasibility and practicality. Data collection techniques in this study include tests in the form of pre-test and post-test work while non-tests include observation, questionnaire filling, interviews and documentation. The results showed that the feasibility value of developing e-modules with PBL syntax provided by media, material and language experts met the criteria with an average validity of 82.53%, 88.51%, and 100% respectively (very valid category). The practicality test by students showed an average practicality level of 93.87% (very practical category). Based on the results of the pre-test and post-test, the development of e-modules with PBL syntax meets the effective criteria, this can be seen from the effectiveness analyzed with the results of a significant increase based on the t test ($t_{hitung} = 5.51 > t_{table} = 2.037$). Thus, this PBL-integrated e-module is declared valid, practical, and effective as Physics learning media, and is able to significantly improve students' concept understanding of sound waves material.

Keywords: E-modul; Physics; Sound Wave; Problem Based Learning.

Introduction

The ongoing development of technology requires humans to carry out digital transformation as an effort to adapt to the current era, namely by utilizing technology to create new, more effective and efficient ways to replace old processes in various aspects of life, including education (Ainun et al., 2022).

One way to form quality human resources is through education, because education plays an important role in determining the progress of a nation. If education is organized properly, the potential of each individual can develop optimally so that they can compete in the future (Mahzuardi et al., 2024). The increasing integration between humans and technology

through the development of digital systems, artificial intelligence, and virtual worlds, makes information and communication technology (ICT) a major force in the renewal of the education system (Doringin et al., 2020). These changes require education to equip students with 21st century competencies, such as critical, creative, collaborative and communicative thinking (4Cs), as well as mastery of the latest technology. For this reason, in order to make learning more interesting and motivate students and focus attention on the topics discussed, it is necessary to select and utilize appropriate and appropriate learning media (Miftah & Rokhman, 2022). Edwin (2024) state that technology has become the main driver in transforming learning that is relevant, interactive, and adaptive to future challenges.

How to Cite:

Sikumbang, N., Jasrial, Ridwan, & Rayendra. (2025). Development of E-Modules Integrate with PBL (Problem Base Learning) in High School Physics Subject Class XI. *Jurnal Penelitian Pendidikan IPA*, 11(6), 423-434. <https://doi.org/10.29303/jppipa.v11i6.11627>

Responding to these challenges, educational institutions are required to not only integrate technology into learning, but also design media that are suitable for the characteristics of digital era learners. Yaumi (2018) emphasizes that the development of learning media that is in line with ICT advances is a strategic step so that graduates have high competitiveness in the world of work. However, the reality in the field shows a gap between the potential of available technology and its use in the learning process. Physics learning, especially in class XI sound waves, is an important topic that requires in-depth concept understanding and scientific thinking skills.

The assessment results of SMA Pertiwi 1 Padang in the 2022/2023 and 2023/2024 school years show that the average student score is still below the KKTP. Based on the results of observations and interviews at SMA Pertiwi 1 Padang, 76.32% of students still have difficulty in understanding concepts on sound wave material at school, even though at school as many as 97.34% of students already have smartphones / mobile phones, but have not been maximally used in the learning process. Available learning media are still limited to textbooks, printed modules, and LKPD. In fact, physics learning requires teaching materials that are interesting, interactive, and encourage independent learning. In this case, e-modules are an effective alternative because they allow the presentation of material through flexible digital media, complete with visualizations, videos, and a coherent learning structure (Faudah, 2016).

E-modules play a strategic role in supporting learning effectiveness, especially in facilitating teachers in delivering material systematically. The main advantage of e-modules over conventional printed learning media lies in their interactive characteristics that allow two-way communication between learners and learning materials (Pramana et al., 2020). This is in line with Linda et al. (2018), which states that the use of interactively designed e-modules is expected to increase student motivation and understanding of learning materials. E-modules are able to train students to learn independently, provide multimedia content, and are user-friendly (Alfarozzi et al., 2023; Amaliyah et al., 2023).

In order for the digital media developed to foster higher order thinking competencies, it is necessary to apply the right learning model. Problem Based Learning (PBL) is one of the effective approaches to develop problem solving skills through active involvement of students in dealing with real problems (Nugraha et al., 2017; Wijayanti et al., 2020). The implementation of e-modules based on problem solving can help learners to solve problems independently so that they get concrete experience in problem solving and foster and train higher order thinking skills (Suarsana & Mahayukti, 2013).

Latifa et al. (2017) explained that PBL encourages learners to identify problems, seek information, evaluate solutions, and apply concepts in a real-world context. The integration of PBL in e-modules not only makes learning more contextual and meaningful, but also supports the principle of learner-centered learning as emphasized in the Merdeka Curriculum. In addition, the use of the PBL model is designed to facilitate students in understanding material concepts through solving problems that are relevant to everyday life, thus, students are expected not only to understand concepts theoretically, but also to be able to apply them in a real context (Pakaya et al., 2023).

This research is important because it offers an innovative solution in the form of developing e-modules based on Problem Based Learning (PBL) on sound waves. E-modules allow the integration of digital content, such as animations and videos, which facilitate the understanding of abstract concepts in physics. Meanwhile, the PBL approach encourages students to be actively involved in learning through solving real problems, thus strengthening higher-order thinking skills and the application of concepts in everyday life.

The novelty of this research lies in combining two important elements, namely digital technology (e-modules) and the PBL approach in the context of high school physics learning. Although each approach has been used separately in various studies, the integration of the two specifically on sound waves material is still very rare, especially in the local context and the implementation of the Merdeka Curriculum. This research is expected to be a model for implementing digital learning that is effective, adaptive, and relevant to the needs of today's students.

Method

Research on the development of a Problem-Based Learning (PBL) integrated e-module in the physics subject for Grade XI of senior high school employs a Research and Development (R&D) approach. As explained by Sugiyono (2021), R&D aims to validate, produce, or improve a product to make it more effective, efficient, and practical. According to Sarpong et al. (2023), R&D is a type of research used to produce a specific product and to test the effectiveness of that product so that it can be functionally applied. Therefore, to generate a product, needs analysis is conducted, and to ensure its broader applicability, effectiveness testing is essential.

Various development models with different stages and characteristics can be used in this type of research, including Borg and Gall, 4D, and ADDIE models. This study adopts the 4D model (Four-Dimensional Model) developed by Thiagarajan, Semmel, and Semmel, which

consists of four stages: Define – analyzing learning needs, student characteristics, and learning materials; Design – designing the e-module based on the results of the analysis; Develop – developing the product, validating it through experts in subject matter, media, and language, and revising it based on feedback; Disseminate – distributing and implementing the product among students (Asif et al., 2021; Cahyadi, 2019; Damarwan & Khairudin, 2017).

Each stage is carried out systematically to ensure the resulting product meets the criteria of being valid, practical, and effective in the learning process. In this study, the researcher applied all four stages of the 4D model. During the Define phase, information was collected through literature studies and field studies. The literature study involved gathering and reviewing relevant sources to form the theoretical foundation for developing the teaching module (Tamaulina et al., 2024). The field study was conducted through observations and interviews with physics teachers and 36 Grade XI students at SMA Pertiwi 1 Padang.

The research instruments used included tools for measuring validity, practicality, and effectiveness. Validity was assessed by experts using validation sheets covering content, language, and media. Practicality was measured through questionnaires distributed to students to assess the ease of use and usefulness of the e-module. Effectiveness was determined by comparing students' pretest and posttest scores.

Data were analyzed using both quantitative descriptive and qualitative descriptive approaches. Qualitative data were obtained from feedback and suggestions, while quantitative data were analyzed using percentage formulas and t-tests to determine the significance of the difference between pretest and posttest scores.

Result and Discussion

Result

The Development of Student Worksheet (LKPD) on Disaster Mitigation and Adaptation Material in Geography Learning for Grade X of Senior High School was carried out through four main stages: Define, Design, Develop, and Disseminate. The outcomes from each stage are described as follows:

Define Stage

The Define stage is the initial step in the development of a Problem-Based Learning (PBL)-integrated e-module. In this stage, the researcher conducted an in-depth analysis to understand the needs, objectives, and context of physics learning for Grade XI

students in senior high school. The following steps illustrate the Define stage in more detail:

Curriculum Analysis

At this initial step, the researcher examined the applicable curriculum to identify the competencies targeted for achievement. Curriculum analysis is essential for determining the specific basic competencies to which the teaching materials will be aligned, recognizing that not all competencies outlined in the curriculum may be supported by corresponding learning resources. In this study, the selected basic competencies were 3.14 and 4.14, as specified in the 2013 Chemistry Curriculum syllabus. The full syllabus can be found in the appendix.

Analysis of Student Characteristics

Based on a survey conducted at SMA Pertiwi 1 Padang, the majority of students expressed a negative perception of physics, with 79% perceiving the subject as difficult and intimidating. Specifically for the sound wave topic, 76.32% of students reported difficulties in understanding the concepts, and 80.24% admitted to being passive during learning activities. Furthermore, 75% of students rated the existing learning materials as unengaging, contributing to a high level of learning fatigue reported by 77.61% of respondents.

Conversely, the use of electronic devices for learning was notably high, with 97.34% of students utilizing smartphones as learning aids. This presents an opportunity to develop digital learning media that aligns with students' habits and needs. Interest in innovative learning media was evident, as 100% of the students expressed willingness to use an e-module for the sound wave topic. Additionally, 96% of students preferred learning materials that include illustrations, videos, and audio elements. Only 23% of students found white as an attractive background color for learning materials, indicating a general preference for more vibrant and visually appealing designs.

These findings highlight the urgent need for the development of interactive, visual, and technology-based learning materials that can improve students' understanding, engagement, and interest in physics learning, particularly in the sound wave topic.

Material Analysis

The physics subject for Grade XI Phase F in the Merdeka Curriculum emphasizes conceptual understanding through scientific and contextual approaches. The learning process is designed to cultivate critical thinking, creativity, collaboration, and communication skills. One of the essential topics is Waves and Sound, which includes the characteristics, types, and real-life applications of sound waves.

Due to its abstract and complex nature, this topic is well-suited to a Problem-Based Learning (PBL) approach that encourages students to actively engage in thinking and solving real-world problems—such as resonance, the use of ultrasound in medicine, and soundproofing in buildings. The Merdeka Curriculum also provides teachers with the flexibility to develop their own teaching materials, including digital e-

modules. E-modules enriched with videos, animations, and interactive simulations, combined with PBL integration, can make learning more contextual and promote students’ problem-solving skills.

Based on the Merdeka Curriculum and the analysis of sound wave material, the structure of the topic is presented in the following table 1.

Table 1. Analysis of Sound Wave Material for Grade XI Physics in the Merdeka Curriculum

Learning Objectives	Indicator	Material
Identify the concepts and principles of sound and light waves apply to various technologies	Analyze te characteristics of mechanical waves	Waves sound waves: sound wave caraccteristics strings and organa pipes resonance and doppler effect.
	Analyze the physical quantities of traveling waves and sattionary waves in everyday events	Light waves: interference, diffraction, and polarization.
	Explain the reflection of waves at the free end and the fixed end	
	Calculate the frequency and speed of propagation of waves on a string using Melde`s experiment	
	Eplain the meaning of resonance, kite, intensity, intensity level and doppler effect	
	Present the results of the experiment and explain its physical meaning	
	Describe the properties of the general characteristics of light waves including interference, diffraction, and polarixation	
Provide examples of the application of the concept of polarizayion in modern optical equipment used in everyday life.		

Thus, the development of PBL-based physics e-modules on class XI material is not only in line with the principles of the Merdeka Curriculum, but also an innovation that can increase student engagement and understanding of physics concepts. This is in line with the opinion of Idhartono (2022) who stated that learning in the independent curriculum emphasizes the use of learning tools that can accelerate the completion of new literacy and create an independent learning education system but still provide character to students. This approach is expected to answer the challenges of 21st century learning and improve the quality of student learning outcomes in a meaningful and sustainable manner.

Formulating Objectives

The learning objectives on sound waves in the development of e-modules integrated with Problem Based Learning (PBL) are to equip students with the ability to understand the basic concepts of sound waves through solving contextual problems that are relevant to everyday life. Through problem-based learning, students are expected to be able to identify the characteristics of sound waves, explain the properties and events related to them such as resonance, reflection, and interference, and analyze the application of sound waves in technology and the environment. In addition, the learning objectives also include developing critical thinking skills, scientific communication skills, and teamwork in completing project-based tasks. With the use of interactive and digital-based e-modules, studentsare expected to learn independently and

collaboratively, and be able to foster curiosity and scientific attitudes that are in line with the Pancasila Student Profile in accordance with the direction of the Merdeka Curriculum.

Design Stage

The design stage is the second stage in the 4D development model, which aims to design an initial prototype of an integrated PBL e-module, including test development, media selection, and initial design. At this stage, several important steps are taken, as follows:

Developing Criteria

The development of evaluation criteria and instruments is an important step in ensuring that e-modules can effectively measure students' understanding of physics concepts. This process begins by referring to learning objectives and detailing measurable indicators. The test format used is multiple choice through pretest and posttest. The questions are designed to measure conceptual understanding, critical thinking skills, and the application of knowledge in diverse contexts, while avoiding ambiguity. The resulting instruments will be used in the Evaluate phase of the Problem-Based Learning (PBL) model to assess students' achievement of learning objectives.

Selecting Learning Media

The selected media format is one that meets the criteria of being interesting, easy to use, and helpful in the learning process. In physics lessons, there is a lot of material that uses visual images to help students better understand the material being taught. Previously, the media format was limited to presentations dominated by text and material from textbooks. Based on this, Android devices can be utilized to implement integrated e-module learning media using PBL (Problem-Based Learning) in physics lessons both inside and outside the classroom (Arifin et al., 2024; Dina et al., 2024; Setyabudi, 2024).

Initial Design

This design is the next step in the development of e-modules, in which a comprehensive learning plan is designed based on PBL (Problem-Based Learning). This process involves designing learning steps that cover several steps or syntaxes. The following are the steps taken in the Design stage is orientation to the problem; the problem must be relevant to the daily lives of students and spark their curiosity. Organizing Students for Learning; teachers facilitate roles and collaboration strategies within learning teams; guiding Independent and Group Inquiry; this stage develops critical thinking skills, information literacy, and collaboration;

developing and Presenting Work Products; analyzing and Evaluating the Problem-Solving Process.

An example of the steps taken in the design stage can be seen in the following figure:

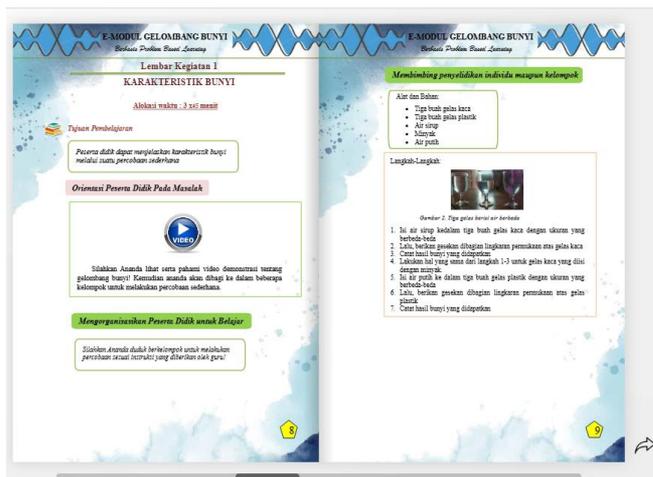


Figure 1. Example of Problem Orientation Stage Display

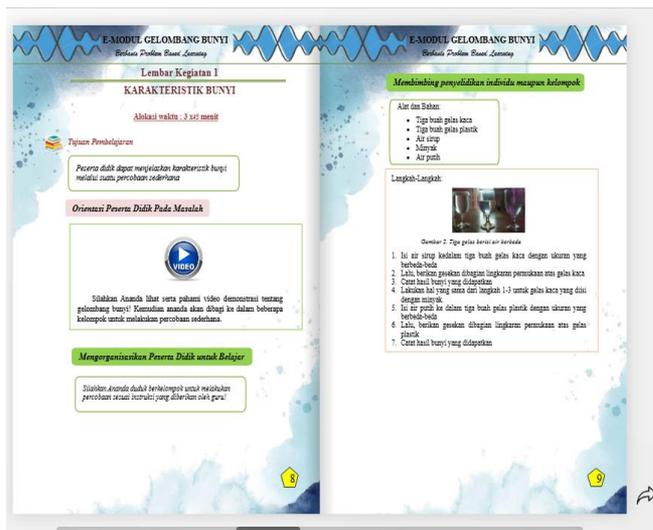


Figure 2. Example of Displaying Stages of Organizing Students



Figure 3. Example Display of Independent and Group Inquiry Stages

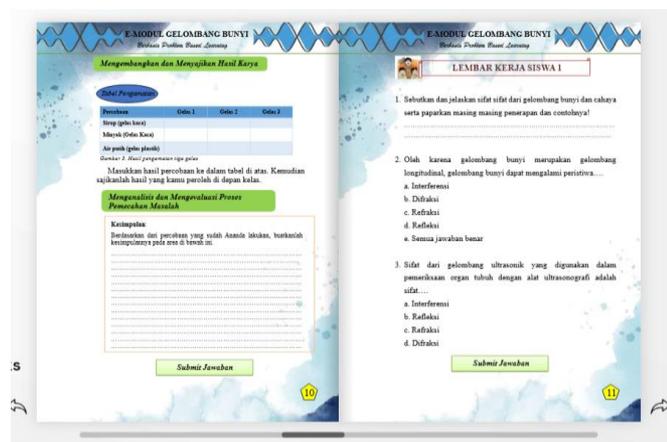


Figure 4. Display Example of Developing and Presenting Work Stages

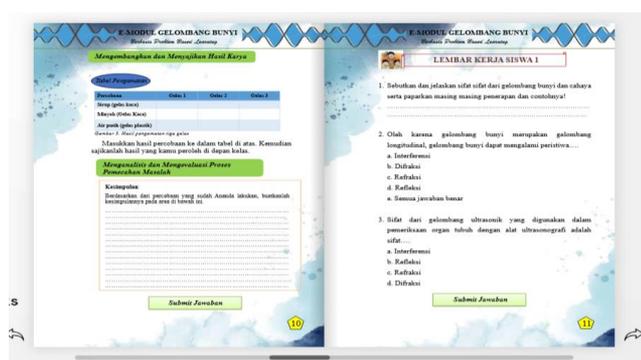


Figure 5. Example Display of Analyzing and Evaluating Stages

Development Stage
Validity Test
Media Validity

The media expert validity test was conducted with postgraduate lecturers from Padang State University who are experts in media. At this stage, the researchers showed the media that had been created, and the media experts provided suggestions and comments. The results of the media experts' assessment are shown in the following table (Hikmawati, 2017; Sukardi, 2013).

Table 2. Result of Media Expert Validation Assessment

Aspect	Validity Score %	Category
Component	75	Valid
Content	75	Valid
Interface	75	Valid
Interactivity	100	Very Valid
Technology	87.52	Very Valid
Average Score V	82.55	Very Valid

From the results of the questionnaire given to media expert validators, the average V score was 82.55%, which is considered valid. Comments or suggestions provided on the assessment sheet by validators can be used as input and guidelines for revising the media. The

comments or suggestions provided are as follows: Add the class and semester on the cover; Enlarge the font size of the initial usage instructions and reduce the size of the icons; Add a Topic Map of the material.

Material Expert Validity

Expert validation data was obtained from a subject matter expert, namely a Physics Lecturer from the Faculty of Mathematics and Natural Sciences, University of North Sumatra. The subject matter expert reviewed the content aspects of the integrated PBL (Problem-Based Learning) e-module that had been designed (Arikunto, 2013). The assessment results covered the components of content, language, presentation, and graphics. The results of the subject matter expert's assessment are shown in the Table 3.

Table 3. Result of Material Expert Validation Assessment

Aspect	Validation Score	Category
Content Component	87.53	Very Valid
Construct Component	84	Very Valid
Language Component	95	Very Valid
Graphics Component	87.57	Very Valid
Average Score	88.56	Very Valid

Based on the validation results by subject matter experts in the table, the average V value obtained was 88.56%, which is considered valid.

Validity of Language Experts

Validity data was obtained from a language expert, namely a lecturer in the Indonesian Language Study Program at the Faculty of Language and Arts, Padang State University, by administering an assessment questionnaire. The language expert reviewed the language aspects of the integrated PBL (Problem-Based Learning) e-module that had been designed. The assessment results covered language rules, sentence appropriateness, and students. The results of the language expert's assessment are shown in Table 4.

Table 4. Result of Language Expert Validation Assessment

Aspect	Validity Score %	Category
Conformity with	100	Very Valid
Language Rules	100	Very Valid
Sentence Suitability	100	Very Valid
Suitability with Learners	100	Very Valid

Based on the table 4 the average value of V from language validation is 100, which is categorized as valid.

Practicality Test

A practical test was conducted on 32 students in class XI at SMA Pertiwi 1 Padang. The practical test was conducted to determine the extent of students' assessment of the learning media that had been created. The data was obtained from the results of the media assessment questionnaire filled out by the students. In addition, the researchers also conducted a socialization program on the functions and uses of the media program that had been created. The researcher also discussed how students would complete the

questionnaire after using the media. After the orientation, the researcher provided each student with a link to the e-module to be accessed on their respective smartphones. The researcher then instructed the students to open the link and use the media, and further instructed them to complete the questionnaire that had been provided (Pramana et al., 2020; Riduwan, 2013). The results of the practicality analysis of the e-module are summarized in the Table 5.

Table 5. Results of Student Practicality Analysis

Aspects assessed	Percentage %	Category
Ease of use		
The questions are clearly presented.	99.21	extremely practical
The language used is easy to understand.	96.00	extremely practical
The font used is clear and easy to read.	96.82	extremely practical
The e-module is practical in size and easy to carry.	96.00	extremely practical
Practicality	97.00	extremely practical
Learning time efficiency		
Learning time is more efficient with e-modules.	93.75	extremely practical
The material provided is in line with the allocated learning time.	92.96	extremely practical
The duration of learning is sufficient to understand the material without rushing.	89.83	extremely practical
Quickly understand the subject matter through the methods used in learning.	89.87	extremely practical
E-modules accelerate my understanding of the material.	93.75	extremely practical
Practicality	92.00	extremely practical
Benefits		
The images, tables, and readings in the e-module motivate me to discover concepts.	90.00	extremely practical
The e-module helps me understand concepts through questions.	93.75	extremely practical
The student worksheets in the e-module measure my understanding of acids and bases.	90.00	extremely practical
The e-module helps me learn independently.	91.40	extremely practical
The answer keys in the evaluations help me measure my abilities.	92.91	extremely practical
The e-module increases my interest in learning.	93.75	extremely practical
I am happy with this e-module.	93.75	extremely practical
I find it easy to learn using the e-module.	95.32	extremely practical
Students are helped by the questions provided in discovering and understanding the concepts being studied.	92.92	extremely practical
Practicality	92.63	extremely practical
Average practicality	93.87	extremely practical

Based on Table 5, it can be seen that the average practicality value is 93.87% with a category of very practical. The integrated PBL (Problem Base Learning) e-module on Sound Wave material is concluded to be practical in terms of ease of use, time efficiency, and benefits.

Effectiveness Test

The effectiveness test aims to measure the level of success of the e-module that has been developed. The effectiveness test was conducted by administering pre-tests and post-tests to 33 students in class XI at Pertiwi 1 High School in Padang. There were 15 objective questions (multiple choice) provided for the pre-test and

post-test with 5 alternative answers. This effectiveness test began with a pre-test administered to students who had studied sound wave material without using the e-module, aiming to assess their understanding/knowledge of sound waves. After the pre-test, the developed e-module was presented to the students. Following this, a post-test was conducted to assess the impact of using the e-module on students' knowledge of sound wave material (Syafri, 2010).

Based on the results of the t-test calculation, the average pre-test score was 15.76. The average post-test score was 79.18. This indicates an increase in scores. Based on the effectiveness test data using the t-test, the calculated t-value was 5.51. Next, the t-table value was

calculated with $df = N-1 = 33-1 = 32$ and $\alpha = 0.05$, resulting in a t-table value of 2.037. It was found that the t-calculated value was greater than the t-table value ($5.51 > 2.037$). Therefore, it can be concluded that there was a significant difference in scores between the pretest and posttest results.

Disseminate Stage

The disseminate stage is the final phase in the development model which aims to disseminate the developed product to a wider scope. At this stage, researchers not only distribute products within the scope of limited trials, but also begin to carry out initial implementation as the first step of dissemination. Products in the form of e-modules integrated with Problem Based Learning (PBL) were distributed to the Vice Principal for Curriculum and Physics subject teachers of grade XI as part of the internal distribution process at school.

Although the distribution of the product was still on a limited scale, this stage became the foundation for wider implementation tests in the next phase. The researcher also informs access to learning media through digital links to allow teachers to do further exploration, as well as provide further feedback on the use of e-modules in real learning contexts. Thus, activities at the disseminate stage in this study include the initial distribution process, product communication to school stakeholders, and exploration for wider adoption to other classes.

This stage also opens up opportunities for the integration of e-modules into regular learning programs if it is considered practical and effective. Therefore, disseminate in this research functioned as the initial stage of expanding the range of product use, as well as a bridge to the potential for larger-scale implementation in the classroom.

Discussion

One of the efforts made to present sound wave material is through the creation of learning media in the form of e-modules. This medium was chosen because it can contain educational videos, animations, images, audio, and virtual laboratories that can be used by students at any time, thereby helping them to understand the concept of sound waves. The electronic learning media that was developed could be applied more effectively in the teaching and learning process compared to conventional learning methods (Abulfattah, 2016).

In addition to selecting learning media, determining the appropriate learning model is also important to facilitate students' understanding of the learning material. The PBL (Problem-Based Learning) integrated e-module is a learning model developed

based on constructivist theory, where students construct their own knowledge and actively participate in every stage of the learning process. This learning model consists of five stages: Problem Orientation, Organizing students for learning, Guiding individual and group investigations, Developing and presenting work outcomes, and Analyzing and evaluating the problem-solving process.

This study aims to develop an e-module on sound wave material to enhance students' critical thinking skills. The data used in this study were obtained directly through validity tests, practicality tests, and effectiveness tests on the research subjects. These tests are important because the developed learning media can only be used in the learning process after being declared valid, practical, and effective (Plomp & Nieveen, 2009).

Validity of integrated PBL e-modules (Problem Base Learning)

The validity of the media was assessed using indicators from Bozkurt & Bozkaya (2015), namely components, content, interface, interactivity, and technology. The results of the expert validator's assessment of the e-module media based on Table 6 showed a score of 75% for the component aspect, which is categorized as valid. This indicates that the components of the developed e-module are complete, clear, and systematically organized. In this context, the components of the e-module refer to the introduction, user guide, materials, evaluation questions, and supporting multimedia (images, audio, and video).

The content aspect received an average score of 75%, categorized as valid. This indicates that the content of the e-module is consistent with the instructional design of the learning process. The suitability of the e-module content significantly influences the interactions that occur during the learning process. Bozkurt & Bozkaya (2015) state that, in essence, e-module interactions are not solely determined by the technology used but are also influenced by the content design.

The interface aspect received an average score of 75%, categorized as valid. This indicates that the e-module display window, such as the placement of navigation buttons, frame design, and color proportions of interactive instructional materials, is very good. The interface usability of these instructional materials significantly impacts the ease of operating the device. Bozkurt & Bozkaya (2015) also note that the interface aspect is related to the usability of the interactive instructional materials developed.

The interactivity aspect achieved an average score of 100% with a valid category. This indicates that the e-module design and its components can create interaction in the learning process. The usability of this interactivity aspect, according to Wijaya (2012), is beneficial in

developing students' cognitive and affective abilities simultaneously.

The technology aspect achieved an average score of 87.53% with a valid category. This indicates that the interactive teaching materials can be used online or offline, using a PC or mobile phone, and feature high-quality images and videos. Based on Table 6, the average score was 82.53% with a valid category. Thus, the integrated PBL (Problem-Based Learning) e-module on sound wave material can be declared technically valid and can be tested.

The next validity test is the validity test of the material assessment aspects, which consists of four aspects, namely content suitability, linguistic components, construct components, and graphic components. The assessment of the content suitability aspect of the integrated PBL (Problem-Based Learning) e-module in the physics subject for Grade XI high school students relates to the structure of the e-module. Based on Table 7, it was found that the average score for the content component was 87.52%, which is categorized as valid. This score indicates that the integrated PBL (Problem-Based Learning) e-module developed is in line with the requirements of learning objective no. 9 in the ATP Kumer. This indicates that the content component aspect includes the suitability of the material contained in the e-module to the learning objectives to be achieved and that the material provided is appropriate to the students' abilities. This is consistent with the theory that content validity indicates that the developed product is in line with the curriculum and based on a strong theoretical rationale (Rochmad, 2012).

Assessment of the language component relates to the use of language by the author in presenting the subject matter of sound waves in the e-module. Based on table , the results of the validator assessment showed an average score of 95%, categorized as valid. This indicates that the sound wave e-module integrated with PBL (Problem-Based Learning) has employed appropriate, simple, and clear language, making it easy for users to understand. According to the Ministry of Education and Culture, a good e-module should use simple and comprehensible language and include common terms so that it is user-friendly.

Assessment of the presentation construction component of the PBL-integrated sound wave e-module, based on Table 7, obtained an average score of 84%, with a valid category. This indicates that the presentation of the developed sound wave e-module has been systematically arranged based on the components of an e-module, in accordance with the e-module development guidelines from the Ministry of Education and Culture (2017). Moreover, the developed sound wave e-module also aligns with the syntax of PBL (Problem-Based Learning).

Assessment of the graphic component of the PBL-integrated sound wave e-module relates to the overall visual appearance or design of the e-module, such as layout, symbols, and illustrations, which must be proportional and attractive. The results of the validator's assessment of the graphic component, as presented in table 5, obtained an average score of 87.52% in the valid category. This shows that the type and size of fonts used in the e-module are appropriate and clearly legible. Images, videos, and virtual labs can be clearly observed. The layout of the e-module is neatly arranged in accordance with the syntax of the PBL model, and the design and color choices are visually appealing. The macroscopic representations used have been adapted to phenomena in real life. This is in line with the statement by Treagust (2008) that macroscopic-level observations can be made through everyday experiences. The submicroscopic representations used in the e-module (Treagust, 2008) already depict macroscopic phenomena at the atomic/molecular level. This is in accordance with the statement by Jansoon et al. (2009) that submicroscopic-level representation is a chemical representation that explains the structure and processes at the particle level of macroscopic phenomena.

The overall average score of material validity was 88,51%, which is categorized as valid. A learning medium meets content validity if all components of the developed learning media are supported by sufficient and mutually reinforcing theoretical foundations to achieve learning objectives (Plomp & Nieveen, 2010).

The next validity test is the language validity test, which includes three components: language rules, sentence structure, and learner suitability. Based on Table 6, the results of the expert language validator assessment of the e-module showed a score of 100% for the aspect of language rules, categorized as valid. This indicates that the language rules of the developed e-module are complete, clear, and systematically structured. In this context, language rules refer to the use of the Indonesian language in accordance with EYD and the Indonesian Dictionary.

The sentence structure aspect obtained an average score of 100%, categorized as valid. This indicates that the sentences in the e-module are in accordance with sentence construction standards as defined in the Indonesian Dictionary. The appropriateness of sentence structure in the e-module significantly influences the interactions that occur during the learning process.

The learner suitability aspect obtained an average score of 100%, categorized as valid. This indicates that the developed e-module is already aligned with the characteristics of students in the Merdeka Curriculum. Based on Table 8, the average score obtained was 100%, in the valid category. Therefore, the PBL-integrated e-module in the subject of Physics for Grade XI of Senior

High School, Phase F, can be declared technically valid and ready to be tested.

Practicality of the PBL-Integrated E-Module (Problem Base Learning)

The practicality test involved students as participants. Based on the data obtained in the appendix, the average percentage score was 93.87%, categorized as very practical. This indicates that the developed e-module is highly practical, meaning that the PBL (Problem-Based Learning) integrated e-module for Grade XI high school physics is practical for use in the learning process.

In terms of ease of use, the e-module obtained an average percentage score of 97%, categorized as very practical. This proves that the PBL-integrated e-module for Grade XI high school physics facilitates students in understanding the topic of sound waves. This finding is in line with one of the characteristics of a good e-module, which is user-friendliness. The ease of use is related to the language of the e-module, which is clear and easily understood by students, and the content that is presented clearly and simply.

In terms of time efficiency, the average percentage score was 92%, categorized as very practical. This indicates that the developed e-module can save learning time, as the PBL stages are structured and allow students to learn at their own pace.

In terms of utility, the average percentage score was 92.63%, categorized as very practical. This indicates that the developed e-module can help students become more independent in discovering concepts from the learning material. Therefore, the PBL-integrated e-module for Grade XI high school physics is beneficial for learning the topic of sound waves.

Effectiveness Test of the PBL-Integrated E-Module (Problem Base Learning)

Based on the results of the t-test calculation, it was found that the average pretest score was 15.76, while the average posttest score was 79.18. This indicates a significant improvement in scores. According to the data from the effectiveness test using the t-test, the calculated t-value (t-count) was 5.51. The t-table value with degrees of freedom ($df = N - 1 = 33 - 1 = 32$) at a significance level of $\alpha = 0.05$ was 2.037. Since the t-count is greater than the t-table value ($5.51 > 2.037$), it can be concluded that there is a significant difference between the pretest and posttest scores.

Conclusion

Based on the results of the research and development conducted, it can be concluded that the e-module integrated with Problem-Based Learning (PBL)

for the Physics subject of Grade XI Senior High School was successfully developed through the systematic stages of the 4-D model (Define, Design, Develop, and Disseminate). This e-module is designed to support a more active, contextual, and student-centered learning process, particularly in understanding physics concepts. The validation results indicate that the developed e-module has a very high level of validity according to expert judgment and is considered highly practical by both teachers and students during classroom implementation. Moreover, the e-module has been proven effective in improving learning outcomes, as evidenced by a significant value of 5.51 in the sound wave topic, reflecting the positive impact of the e-module on students' competence achievement. Therefore, this PBL-based e-module is deemed appropriate to be used as an innovative alternative learning medium to support the physics learning process at the senior high school level.

Acknowledgments

Thanks to all parties who have supported the implementation of this research. I hope this research can be useful.

Author Contributions

Data curation: J.; writing—review and editing: R. R.; visualization: J.; All authors have read and agreed to the published version of the manuscript.

Funding

Researchers independently funded this research.

Conflicts of Interest

The authors declare no conflict of interest.

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