JPPIPA 9(12) (2023)

Jurnal Penelitian Pendidikan IPA
Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

STEAM Approach to Students' Critical Thinking Ability on the Concept of Sound Waves for Developing PBL Model Learning Tools

Yuliyanti Kohohon[1], Mursalin[2], Muhammad Yusuf[2], Masri Kudrat Umar[2], Tirtawaty Abdjul[3*], Ritin Uloli[2]

[1] Master of Physics Education Study Program, Postgraduate Program, Universitas Negeri Gorontalo, Gorontalo, Indonesia.
[2] Physics Education Study Program, Faculty of Mathematics and Natural Sciences, Universitas Negeri Gorontalo, Gorontalo, Indonesia
[3] Science Education Study Program, Faculty of Mathematics and Natural Sciences, Universitas Negeri Gorontalo, Gorontalo, Indonesia.

Received: October 30, 2023
Revised: November 15, 2023
Accepted: December 20, 2023
Published: December 31, 2023

Corresponding Author:
Tirtawaty Abdjul
tirtawaty@ung.ac.id

DOI: 10.29303/jppipa.v9i12.6776

Abstract: One learning model that supports improving critical thinking skills and developing 21st century education is the PBL model. This research aims to describe the quality of the STEAM approach-based PBL model learning tools development for Students' Critical Thinking Ability on the concept of sound wave using the ADDIE development model. The results of the validation carried out by three validators obtained an average percentage for the learning implementation plan of 93.08%, student activity sheets of 92.58%, teaching materials of 90.82%, and critical thinking tests of 92.72%, and all included in the very valid criteria. The practicality of learning tools is seen from learning implementation of 90.72% with excellent criteria, the student's response to the learning tools was very positive with the ease aspect percentage of students' responses was 86.67%, the enthusiasm aspect percentage of 93.33%, the motivated aspect percentage of 86.67% and the involvement aspect percentage of 83.33%. The effectiveness of learning tools in student activity of 91.67% with excellent criteria, the results of the critical thinking test increased by 49.00%, from previously the overall average score of students was 30.33% to 79.33% and the effectiveness category through the N-Gain test was 0.71 with high criteria.

Keywords: Critical thinking; PBL model; Sound waves; STEAM.

Introduction

The importance of education in the 21st century requires students to be able to develop skills, innovate, and master the use of technology and information media. These skills can help survive using life skills (Murti, 2015; Afandi et al., 2016). One way to do this is to organize learning that encourages students to think critically. This method can be implemented through the STEAM (Science, Technology, Engineering, Arts, and Mathematics) learning method. Project-based STEAM learning trains students to appreciate the collaboration between art and science and to apply critical thinking, creativity, and imagination skills to understand real-world challenges (Utomo et al., 2023; Bassachs et al., 2020; Wilson & Hawkins, 2019; Haddar et al., 2023; Anggraeni, 2021; Sha et al., 2021).

Critical thinking is a comprehensive procedure that enables individuals to assess the evidence, assumptions, reasoning, and language that form the foundation of others' thought processes. In addition, critical thinking involves an in-depth approach to information through investigation, exploration, experimentation, and so on to reach accurate conclusions, resulting in the construction of meaningful knowledge. The critical thinking process can be described as interpretation, analysis, evaluation, inference, and explanation (Putri et al., 2023; Rahmawati et al., 2019; Syukri et al., 2022; Guamanga et al., 2023). Conventional and monotonous learning models result in students needing more time to explore their abilities.

How to Cite:
Kohohon, Y., Mursalin, Yusuf, M., Umar, M. K., Abdjul, T., & Uloli, R. (2023). STEAM Approach to Students' Critical Thinking Ability on the Concept of Sound Waves for Developing PBL Model Learning Tools. *Jurnal Penelitian Pendidikan IPA*, *9*(12), 11613–11624. https://doi.org/10.29303/jppipa.v9i12.6776

One of the schools that applies this kind of learning model is SMA Negeri 3 Luwuk. There needs to be improvements and creativity to make learning more attractive to students as the main subject of education and develop critical thinking skills. Lesson material that can be used in developing critical thinking skills is sound waves. This material is straightforward for students to understand based on Problem-Based Learning (PBL) (Fuadi, 2023; Ansumarwaty & Hikmawati, 2023; Mabruroh & Suhandi, 2017; Cahyani et al., 2023).

The PBL model supports improving thinking abilities. PBL, established by the Ministry of Education, Culture, Research and Technology in the 2013 curriculum, is a PBL model that consists of a series of activities where groups or individuals are required to think, communicate, explore, and solve problems by thinking scientifically (Marhamah et al., 2020; Putri et al., 2021; Nagarajan & Overton, 2019; Ismail et al., 2018).

According to the provided information, the researcher discusses the excellence in creating educational resources through the implementation of the PBL model with a STEAM approach toward students' critical thinking abilities on the concept of sound waves.

Method

The research activities were located at SMA Negeri 3 Luwuk, Luwuk District, Banggai Regency, Central Sulawesi Province. This form of research is categorized as development research (R&D) in Figure 1, a methodology employed to create particular products and assess their effectiveness through testing. In this development research, the researcher aims to develop a tool consisting of a Learning Implementation Plan, Student Worksheets, Teaching Materials and Critical Thinking Tests (Sugiyono, 2019).

Figure 1. Flow chart of research

Based on Figure 1, the research utilizes the ADDIE development model, which serves as a framework for constructing effective, efficient, dynamic training program tools and infrastructure that enhance the performance of the conducted training. The ADDIE model encompasses five phases: Analysis, Design, Development, Implementation, and Evaluation.

Data collection techniques and instruments in research consist of several aspects, namely, the validity of using learning device validation sheets, The feasibility of employing observation sheets for learning implementation and questionnaires to gauge student responses and the efficiency of utilizing observation sheets for student activities and test sheets (pretest and posttest) are under consideration, which are adapted to critical thinking indicators, namely analysis, interpretation, explanation, evaluation, and inference. The applied data analysis method involves a descriptive assessment of the validity, practicality, and effectiveness of the learning tools. Validation results are derived from scoring the evaluation of the learning tools by the validator, utilizing a Likert scale with a scoring range from 1 to 4. Then, the validation results, whose percentages are already known, will be matched by looking at the criteria in Table 1 (Akbar, 2013).

The assessment of the practicality of the developed learning tools in this study was determined through an examination of learning implementation and an evaluation of student responses. The analysis of learning implementation involves two choices, namely "Yes" or "No." The interpretation of criteria for evaluating learning implementation involves comparing the results with the average total score, which has been calculated using a formula and then given with the criteria as shown in Table 2 (Sukardi, 2013).

Table 1. Validity Criteria for Learning Tools

Percentage (%)	Validation Criteria
85.1 - 100	Very Valid
70.1 – 85	Enough Valid
50.1 – 70	Less Valid
0.1 – 50	Invalid

Table 2. Criteria for implementing learning

Value Range (%)	Interpretation
86 - 100	Excellent
76 – 85	Good
66 – 75	Enough
56 – 65	Less
0 – 55	Not much

Student responses were obtained from questionnaire results, which were analyzed descriptively by describing the reactions of students to the developed learning tools. The results of the description of the student questionnaire are then made into a conclusion. The scoring for each answer to this questionnaire uses a Likert scale. Furthermore, for quantitative analysis, students' responses can be given a score as indicated in Table 3 (Sugiyono, 2019).

The evaluation of student responses involves interpreting the criteria by comparing the results with the average total score, which has been calculated using a formula and then given with the criteria as shown in Table 4 (Khabibah, 2006).

Table 3. Scoring Guidelines for Student Response Questionnaires

Answer Choices	Positive Statement	Negative Statement
strongly agree	5	1
Agree	4	2
Enough	3	3
Less	2	4
Not much	1	5

Table 4. Student Response Criteria

Percentage (%)	Criteria
86 - 100	Very Positive
71 - 85	Positive
51 - 70	Less
0 - 50	Not much

Learning tools are practical if the learning objectives can be achieved according to specific criteria and influence all student learning outcomes as expected or exceed the specified minimum completeness criteria (Chairunnisa et al., 2022). In the effectiveness analysis, the learning tools developed were obtained based on two aspects: Analysis of student activities in learning and Analysis of students' critical thinking tests.

The interpretation of criteria for evaluating student activity is done by comparing the outcomes with the average total score across three learning sessions, which have been calculated using a formula and then given with the criteria as shown in Table 5 (Sukardi, 2013).

Table 5. Criteria for Student Activities

Value Range (%)	Interpretation
86 - 100	Excellent
76 – 85	Good
66 – 75	Enough
56 – 65	Less

The magnitude of the influence of using the PBL model based on the STEAM approach on improving students' critical thinking abilities is the use of N-Gain (normalized-Gain) analysis. The N-Gain score obtained is the result of a comparison between the average pretest and posttest. The interpretation of the N-Gain value is provided in Table 6 (Hake, 1998).

Table 6. Interpretation of N-Gain Values

Value (g)	Interpretation
$(g) > 0.7$	High
$0.3 \leq (g) \leq 0.7$	Medium
$(g) < 0.3$	Low

Result and Discussion

Result

The creation of learning tools for the PBL model, incorporating the STEAM approach to enhance students' critical thinking skills in the context of sound wave material, is a form of Research and Development (R&D). This process follows the ADDIE development model formulated by Dick and Carey, which includes five stages, namely Analysis, Design, Development, Implementation, and Evaluation. This research aims to produce a product, namely a learning tool using a PBL model based on a STEAM approach that is of quality in terms of validity, effectiveness and practicality data.

Analysis

At this stage, a needs analysis is carried out, along with an analysis of the physics curriculum/syllabus and an analysis of student characteristics. The results of the needs analysis obtained based on face-to-face interviews with class XI physics teachers at SMA Negeri 3 Luwuk stated that the teacher's handbook is only one source of teaching materials, the learning model carried out by the teacher uses cooperative learning, the learning method used by the teacher uses the lecture method, students use student worksheets; and Books. After conducting a needs analysis, then carry out a curriculum analysis of the physics curriculum/syllabus. In this analysis, the researcher chose Sound Waves material for class XI, even semester, with Basic Competencies 3.10 and 4.10. Core Competencies and Basic Competencies which refer to the 2013 curriculum. Then, the researchers carried out an analysis of student characteristics based on students' cognitive background, learning motivation, age, which influences students' cognitive abilities, and the language used by students

Design

At this stage, the researcher begins to prepare the test. The test is prepared based on an analysis of the physics curriculum/syllabus outlined in the learning objectives. In its preparation, it is adjusted to indicators of critical thinking skills, namely interpretation, analysis, evaluation, inference and explanation. The test is made in multiple choice form. Then, the format is selected by designing the learning presentation by selecting the learning model and approach as well as learning resources. In its presentation, the researcher used the model and approach of a PBL learning model based on the STEAM approach. The learning resources used are teaching materials and other relevant physics books. After that, the researcher carried out the initial design by designing learning tools, namely Learning Implementation Plans, Student Activity Sheets, Teaching Materials, and Critical Thinking Tests using a PBL learning model based on the STEAM approach.

Development

Learning tools have been designed, developed, and validated by expert validators consisting of language experts and material experts who will provide an assessment of the learning tools developed by researchers. Assessments consist of qualitative assessments and quantitative assessments. This validation was carried out in a Focus Group Discussion (FGD), which presented expert validators according to their respective fields of expertise. The results of the FGD in the form of suggestions and input from expert validators/experts will be used as material for revision or improvement before conducting research with the aim of improving the tools and achieving the research objectives. The things that are validated by expert validators are validation of the content of learning tools or validation of material and validation in terms of the language used. Before the learning tools are implemented, a readability test will be carried out. This was done to test the extent to which the tools developed by researchers can be read and understood by students. Readability trials were carried out on 6 class XI students at SMA Negeri 3 Luwuk.

Implementation

At this stage, the device has been validated and revised by an expert validator, and then it is ready to be implemented. In this research, the device was only tested on a small (limited) scale, namely 30 students in class XI MIPA B SMA Negeri 3 Luwuk. Researchers gave a pretest before treatment, carried out the treatment, gave a posttest, and gave response questionnaires to students. At each meeting, the observer fills out a device assessment instrument that has been prepared to assess the practicality and effectiveness of the learning device. In this research, researchers conducted three learning activity meetings.

Evaluation

During this phase, an evaluation of the learning tools' development outcomes takes place. This assessment occurs through two methods: formative evaluation and summative evaluation. Formative evaluation involves experts conducting assessments using validation sheets, along with evaluations from both teachers and students. At the same time, summative assessments are carried out at the end of learning (three meetings). This evaluation stage aims to provide feedback and then revise it again if something is missing or has not been fulfilled so that the results of the revision produce a quality (valid, practical and effective) learning tool. The final result of the learning device that has been revised at this stage is called the final device or final product.

Validation of Learning Tools

The initial learning tools that have been designed are validated by experts/experts through FGD. The FGD that was held presented experts or specialists. All experts or validators comment on the learning tools and provide suggestions for improving the learning tools. After going through several revisions by validators, the learning tools developed have now been adapted to the input and improvements provided by each validator. Apart from providing input, the validators also assess the learning tools that have been developed by filling in assessment forms that researchers have prepared. The evaluation results from the validators can be described in detail in Table 7.

Table 7. Average Percentage of Validation Results by Expert Validators

Validation Instrument	Percentage (%)	Criteria
Learning Implementation Plan	93.08	Very Valid
Student Activity Sheets	92.58	Very Valid
Teaching materials	90.82	Very Valid
Critical Thinking Test	92.72	Very Valid

Based on the information listed in Table 7, the learning tools developed by researchers show a high level of validity and can be applied in further testing stages. This conclusion is based on the percentage of validation results that, on average, fall into the very valid category, as evaluated by validators who have expertise in the related field.

Practicality of Learning Tools

The practicality of learning tools for the PBL model, integrating the STEAM approach, is evaluated through two dimensions: the execution of the learning process and the feedback from students.

The assessment of the learning process includes observation across three phases: initial activities, core activities, and concluding activities. Observations of learning implementation were carried out by two observers, namely the physics teacher at SMA Negeri 3 Luwuk and the researcher using a learning implementation observation sheet. The learning on sound wave material was carried out at SMA Negeri 3 Luwuk class XI MIPA B. This observation was carried out out in three meetings. The results obtained from observers can be seen in Figure 2. Based on Figure 2, the implementation of PBL model learning based on the STEAM approach is in the excellent category, with an overall average of 90.72%. The first meeting resulted in an average percentage of learning implementation of 86.37%, the second meeting resulted in an average percentage of learning implementation of 89.77%, and the third meeting had an average percentage of learning implementation of 96.02%.

Student response questionnaires were distributed to 30 students who had been taught with PBL model learning tools based on the STEAM approach. The distribution of this questionnaire occurred following the completion of all learning activities, namely the first meeting to the third meeting, and a learning outcomes test in the form of a critical thinking test in Figure 3.

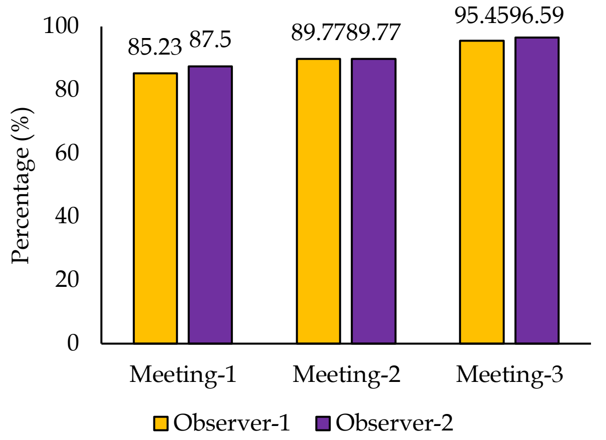

Figure 2. Graph of Percentage of Learning Implementation

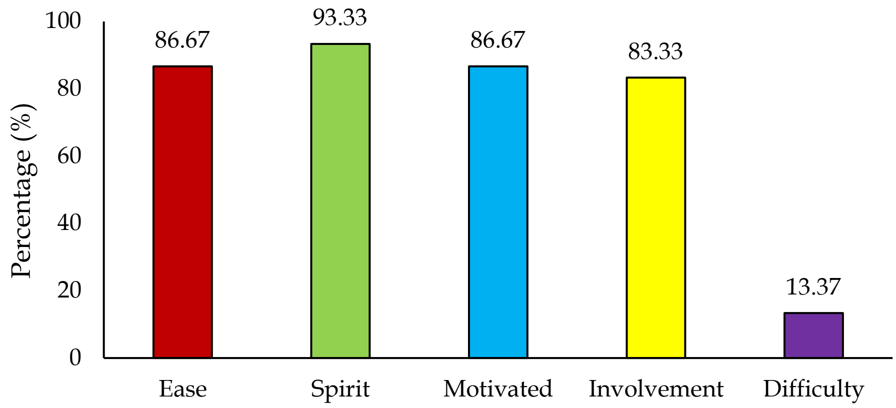

Figure 3. Graph of Student Response Percentage

Based on Figure 3, it can be explained that in the ease aspect, the percentage of student responses was 86.67%; in the enthusiasm aspect, the percentage of student responses was 93.33%; in the motivated aspect, the percentage of student responses was 86.67%; in the involvement aspect, the percentage of students was 83. .33%, and the difficulty level aspect, the percentage of student responses was 13.37%. Based on these results, the PBL learning model based on the STEAM approach used by researchers can provide convenience, enthusiasm, motivation and involvement of students in learning activities.

Effectiveness of Learning Tools

The practicality of PBL model learning tools based on the STEAM approach is viewed from two aspects, namely student activities and critical thinking tests. The purpose of the student activity observation sheet is to evaluate the efficiency of the developed learning tools by assessing student engagement during the learning process. Observations were carried out in three meetings. The results obtained from observers can be seen in Figure 4.

Based on Figure 4, student activity in PBL model learning based on the STEAM approach is in the excellent category, with an overall average of 91.67%. The first meeting had an average percentage of student activity of 87.50%, the second meeting had an average percentage of student activity of 90.91%, and the third meeting had an average percentage of 96.59%.

The critical thinking test of students in this study was obtained through a multiple-choice test with ten questions given to 30 students after going through three learning or treatment activity meetings. This critical thinking test was carried out to determine the level of effectiveness of the PBL model learning tools based on the STEAM approach that had been developed. Before carrying out the treatment, the researcher gave a pretest to the students as an initial score, which aimed to determine the students' critical thinking abilities as a comparison material for whether the learning tools developed by the researchers were practical or not after the treatment was carried out. After the learning tools were developed, the researcher gave a posttest to students as an evaluation of the learning activities that had been carried out. The average results of pretest, posttest and N-Gain can be seen in Table 8.

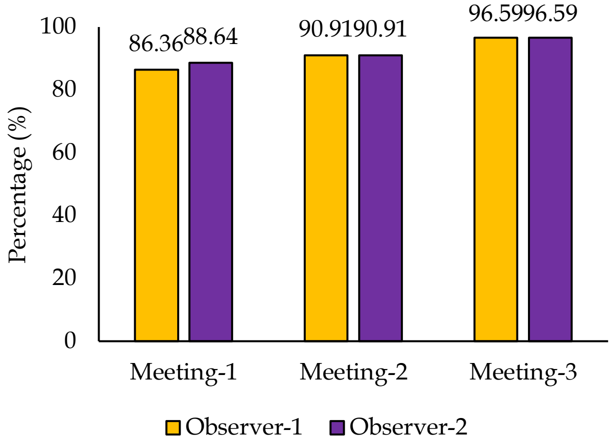

Figure 4. Graph of Student Activity Percentage

Table 8. Percentage of Critical Thinking Tests

Pretest	Posttest	N-Gain	Criteria
30.33	79.33	0.71	High

Table 8 shows that the average pretest score was 30.33%. After treatment, there was an increase in critical thinking skills by 49.00% to 79.33%, meeting the good criteria, as well as the overall average score of students' critical thinking test results on the model. PBL based on the STEAM approach using N-Gain analysis was 0.71 and met the high criteria.

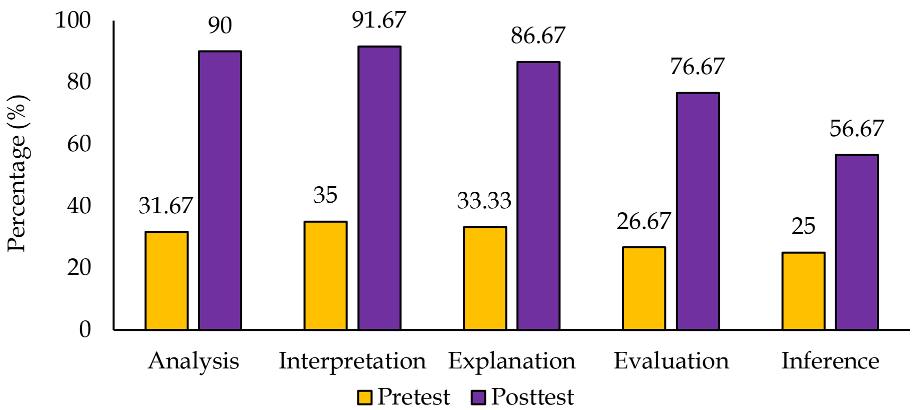

Figure 5. Graph of Students' Critical Thinking Ability

The average results of the student's critical thinking ability pretest answers are based on Figure 5, that the highest percentage is the interpretation indicator of 35.00%, the explanation indicator of 33.33%, the analysis indicator of 31.67%, the evaluation indicator of 26, 67% and the lowest inference indicator was 25.00%. The average results of the post-test answers on students' critical thinking ability showed that the highest percentage of indicators were interpretation indicators at 91.67%, analysis indicators at 90.00%, explanation indicators at 86.67%, evaluation indicators at 76.67%, and the lowest inference indicator was 56.67%.

Discussion

Development research is a systematic series of actions aimed at creating a novel product or enhancing an existing one, with the outcomes being measurable and verifiable. In development research, researchers are faced with the steps of designing, compiling, and implementing a particular product to be tested and then revised. This explanation illustrates that to produce quality learning tools, development needs to be carried out gradually and continuously by going through various stages of testing and revision until a better learning tool is produced (Sugiyono, 2016).

The quality of the developed learning tools is determined by their adherence to three criteria: validity, practicality, and effectiveness (Rahayu, 2016). Based on the explanation above, in this research, validation analysis, practicality analysis, and effectiveness analysis have been carried out on the PBL model learning tools based on the STEAM approach developed in this research. The learning tools in question are Learning Implementation Plans, Student Worksheets, Teaching Materials and Critical Thinking Tests.

Validity of Learning Tools

The validity of using learning tools is determined by professional judgment and a thorough evaluation of each element of the tools that have been developed. The aspects examined by experts involve the construction, content, language and presentation of each learning tool instrument. In accordance with Fatmawaty's perspective (as quoted in Hadis et al., 2022), the suitability of the relationship between the components in the development of learning tools and the characteristics of the learning model integrated into the learning process will determine the level of validity of the learning tools (Buhungo et al., 2021; Hadis et al., 2022).

Based on the results of the assessment of learning tools using the STEAM approach in the PBL model, a number of notes have been provided by the validator as a guide for improvements that researchers will make. Evaluation by experts of each component of the learning tool, including the Learning Implementation Plan, Student Activity Sheets, teaching materials, and critical thinking skills tests, provides a comprehensive picture involving in-depth analysis and recommendations for improvement. Within the framework of evaluating the Learning Implementation Plan, several aspects are the focus of improvement. According to the expert's assessment of the Learning Implementation Plan, the first suggestion for improvement highlights the use of sentences with subject, predicate, object and adverb patterns that are in accordance with Indonesian grammatical norms. The second suggestion for improvement emphasizes phase 1 of preliminary activities, where the teacher's activities in presenting the problem need to be explained more specifically. The third suggestion is related to improvements to Competency Achievement Indicators, which must be described in accordance with Basic Competencies, and the fourth suggestion for improvement emphasizes the principle of formulating learning objectives that include ABCD elements (Audience, Behavior, Condition, and Degree).

Expert evaluation of the Learner Activity Sheet highlighted two leading suggestions for improvement. The first suggestion for improvement emphasizes the importance of developing Student Activity Sheets that better reflect the application of the PBL model in the learning process. The second suggestion for improvement highlights the need to ensure that the issues raised in the Learner Activity Sheet are in line with the learning objectives.

Expert assessment of teaching materials emphasizes the need to improve the quality of images by ensuring the clarity and reliability of image sources, as well as verifying that the information conveyed through images can be appropriately understood by students. Therefore, in the process of updating teaching materials, it is essential to ensure that the sources used for images and other content can be verified and have a high level of accuracy. The use of reliable sources will increase the credibility of teaching materials and ensure that students can rely on the information presented.

Expert assessment of the Critical Thinking Skills Test resulted in the first recommendation for improvement related to the test's consistency with critical thinking indicators. Therefore, it is essential to ensure that each question on the test accurately measures the various aspects of the critical thinking skills it is intended to test. Question modifications are required to match the critical thinking indicators that have been established. The second improvement recommendation highlights the importance of adjusting the difficulty level of questions. Therefore, it is necessary to revise the difficulty level of the questions to ensure that the test can thoroughly identify and measure the level of students' critical thinking skills. This adjustment involves further analysis of the relative difficulty level of each question and adjusting the difficulty level as needed. Following input and suggestions from several validators, researchers carried out revisions as an improvement step. As a result, the learning tools that have been developed are considered valid after several changes and meet the very valid criteria, so they are ready to be used at the next stage.

Practicality of Learning Tools

The practicality of learning tools is obtained through analysis of learning implementation and student response questionnaires in the learning process. The learning tools developed are practical if experts or practitioners state that the learning tools can be applied and used in the field. The practicality of learning tools in this research consists of two aspects, namely, analysis of learning implementation and analysis of student response questionnaires (Chairunnisa et al., 2022).

Based on the observation sheet on the implementation of learning carried out by two observers on the researcher, the results obtained were that for observer one at the first meeting, the researcher did not carry out three learning steps out of a total of 22 learning steps, thus obtaining a learning implementation percentage of 86.36%. Furthermore, for the second meeting, based on observer 1's observations, the researcher did not carry out two learning steps out of a total of 22 learning steps, thus obtaining a learning implementation percentage of 90.91%. Furthermore, for the third meeting, based on observer 1's observations, the researcher carried out all the learning steps, totaling 22, with a percentage of 100%. Apart from that, based on the learning implementation observation sheet carried out by observer two at the first and second meetings, the researcher did not carry two learning steps out of 22 total learning steps, thus obtaining a learning implementation percentage of 90.91%. Next, for the third meeting, the researcher carried out all the learning steps with a learning implementation percentage of 100% for each. Based on the observations of the two observers during the learning process, which was carried out over three meetings, the average percentage of learning implementation was 93.08% in the excellent category.

This excellent category in terms of learning implementation reflects the high level of practicality of the learning tools developed. A high level of implementation can support learning effectiveness, increase student participation, and create a stimulative learning environment (Ramdani et al., 2019). Therefore, the observation results, which show the implementation of learning in the excellent category, provide empirical support for the practicality of PBL model learning tools based on the STEAM approach in improving the learning process. In reviewing aspects of the PBL learning steps, the results of observations showed that the implementation of learning in the first to third meetings reached the excellent category. The PBL learning steps implemented, such as student orientation to problems, group formation, independent exploration, and presentation of results, are implemented with a high level of implementation.

Meanwhile, aspects of the STEAM approach to learning also show a high level of implementation. Observations at the three meetings reflect good integration between science, technology, arts, engineering and mathematics in the learning process. STEAM steps are applied consistently, such as identifying complex problems, using technology as a tool, and integrating art elements. The results of this research also show the suitability of integrating the STEAM approach into PBL learning. Observations at the third meeting, which achieved the highest implementation, showed that teachers were able to integrate STEAM principles more deeply as time went by. Thus, these results provide empirical support for the successful integration of the STEAM approach in the development of learning tools.

Overall, the results of this research strengthen empirical evidence regarding the practicality of PBL model learning tools based on the STEAM approach. The high level of learning implementation, especially at the third meeting, shows that this approach can be implemented effectively and efficiently in the context of Sound Wave learning. By referring to literature findings and previous research results, the learning tools developed are able to create a learning environment that supports, challenges and motivates students.

Apart from the implementation of learning, the practicality of learning tools is measured using a student response questionnaire. The student response questionnaire to the PBL model based on the STEAM approach received a very positive response from students. The results of students' responses to the learning tools developed based on the results of the questionnaire describe the positive impact on the practicality of these learning tools. In particular, in the aspect of convenience, students gave a response percentage of 86.67%, indicating that the learning tools were considered easy to understand and implement. Ease of use of learning devices can increase student interest and participation (Dewi & Akhlis, 2016).

The enthusiasm aspect, with a student response percentage of 93.33%, shows the high level of motivation generated by the learning tools. These positive results show that the STEAM-based PBL approach can stimulate students' enthusiasm for learning. In the motivated aspect, the percentage of student responses was 86.67%. PBL learning approaches that are interesting and relevant to students' daily lives can increase their motivation in learning (Suari, 2018).

Even though the percentage of student responses in the aspects of involvement and level of difficulty was 83.33% and 13.37%, respectively, these results can still be interpreted as positive. High student involvement reflects the effectiveness of learning tools in maintaining active participation. At the same time, a low level of difficulty can indicate the ease of students carrying out each step of PBL learning based on the STEAM approach. Overall, the results of the student response questionnaire confirmed that this learning tool was practical and received positive responses from students. By referring to literature findings and previous research results, it can be concluded that PBL model learning tools based on the STEAM approach can motivate, involve and support student learning effectively.

Effectiveness of Learning Tools

The effectiveness of the PBL model learning tools based on the STEAM approach that was developed was seen from the students' activities, which two observers observed through observing all students' activities at the learning stages or steps, including preliminary activities, core activities, and closing activities. The results of observations of student activities in learning show a high level of effectiveness of learning tools, with an average percentage of 91.67% and an excellent category. Observations were carried out in three meetings, producing consistent data describing the level of student participation and involvement. At the first meeting, student activity reached an average percentage of 87.50%, indicating a good level of participation in STEAM-based PBL model learning. Increased activity was seen at the second meeting, where the average percentage reached 90.91%, and it reached its peak at the third meeting, with an average percentage of 96.59%.

Factors supporting the effectiveness of student activities in learning can be identified through the context of these observations. First, the PBL model provides space for students to actively participate in solving problems, collaborating with group friends, and developing solutions. The application of PBL in learning can increase the level of student participation and create an interactive learning environment. Second, the STEAM approach to learning provides an additional dimension that supports student engagement (Putri et al., 2015). The STEAM approach to learning provides an additional dimension that supports student engagement. The integration of science, technology, art, engineering and mathematics creates diverse and exciting learning (Nurhikmayati, 2019).

At the third level, the percentage of student activity reached 96.59%, indicating the peak of student involvement in learning. This can be caused by students' adaptation to the teacher's learning model and teaching style, along with the progress of learning that occurs. Factors such as adaptation and progressiveness in learning can increase the level of student engagement (Zubaidah, 2019). Thus, the results of observing student activities in learning provide a positive contribution to understanding the effectiveness of learning tools. By referring to previous literature and research findings, the combination of the PBL model and the STEAM approach can create a learning environment that is dynamic, interactive, and supports student involvement.

The effectiveness of the PBL model learning device product based on the STEAM approach that was developed, apart from being reviewed in terms of analyzing student activities, was also analyzed, as well as the results of critical thinking tests. The results of the critical thinking test are determined by the effectiveness category through the N-Gain test of 0.71 with high criteria. The average results of the pretest answers to critical thinking skills in students show that the highest percentage is the interpretation indicator of 35.00%, the explanation indicator of 33.33%, the analysis indicator of 31.67%, the evaluation indicator of 26.67% and the lowest inference indicator is 25.00%. The average results of the post-test answers on students' critical thinking ability showed that the highest percentage of indicators were interpretation indicators at 91.67%, analysis indicators at 90.00%, explanation indicators at 86.67%, evaluation indicators at 76.67%, and the lowest inference indicator was 56.67%. Based on the results of calculating critical thinking indicators, there has been an increase in students' critical thinking abilities.

PBL model learning tools based on the STEAM approach have succeeded in proving their effectiveness in improving students' critical thinking skills. This increase can be explained through supporting factors that specifically influence each indicator of critical thinking skills. First, in the aspect of interpretation, the PBL approach provides space for students to interpret information in depth through problem-solving and independent exploration (Akmalia et al., 2016). Second, in the analytical aspect, PBL encourages students to analyze information more critically, and collaboration in groups broadens the analytical perspective (Habibah et al., 2022).

In the explanation aspect, the STEAM approach facilitates students' ability to explain complex concepts through a creative and interdisciplinary approach involving art, engineering and science (Kurnia, 2021). Despite improvements in inference aspects, supporting factors may require additional approaches. Developing inference skills requires providing opportunities for students to make conclusions and relate existing information by emphasizing the importance of inference skills in critical thinking, which can be used as a basis for identifying steps for improvement in this aspect. Thus, this learning tool has holistically created a learning environment that stimulates and supports the development of students' critical thinking skills. These findings are in line with literature that highlights the effectiveness of the PBL approach and STEAM integration in improving students' critical thinking abilities (Facione, 2011).

Conclusion

Based on the description of the discussion regarding research on the development of PBL model learning tools based on the STEAM approach towards students' critical thinking abilities in sound wave material using the ADDIE development research model, it has met valid, practical and effective aspects for use in learning. Obstacles or constraints were found during the implementation of the PBL model based on the STEAM approach. The obstacle faced is the use of insufficient time in the learning process, so the learning process cannot be completed according to the allocated time. This is because students still need to become familiar with the PBL model learning process based on the STEAM approach.

Acknowledgments

Thank you to the principal, teachers, and students at SMA Negeri 3 Luwuk for their assistance and participation so that this research was carried out correctly.

Author Contributions

Yuliyanti Kohohon: Conceptualization, writing—original draft preparation; Mursalin: Methodology; Muhammad Yusuf: Validation; Masri Kudrat Umar: Methodology; Tirtawaty Abdjul: Curation, writing—review and editing; Ritin Uloli: Formal analysis, validation.

Funding

This research received no external funding.

Conflicts of Interest
The authors declare no conflict of interest.

References

Afandi, A., Junanto, T., & Afriani, R. (2016). Implementasi digital-age literacy dalam pendidikan abad 21 di Indonesia. *Prosiding SNPS (Seminar Nasional Pendidikan Sains)*, 3, 113-120. Retrieved from https://jurnal.fkip.uns.ac.id/index.php/snps/article/view/9820

Akbar, S. (2013). *Instrumen Perangkat Pembelajaran*. Bandung: PT. Remaja Rosdakarya.

Akmalia, N. N., Pujiastuti, H., & Setiani, Y. (2016). Identifikasi Tahap Berpikir Kreatif Matematis Melalui Penerapan Model Problem-Based Learning Dengan Tugas Pengajuan Masalah. *JPPM (Jurnal Penelitian Dan Pembelajaran Matematika)*, *9*(2). http://dx.doi.org/10.30870/jppm.v9i2.996

Anggraeni, R. E. (2021). The Analysis Of The Development Of The 5E-STEAM Learning Model To Improve Critical Thinking Skills In Natural Science Lesson. *Journal of Physics: Conference Series*, 1832(1), 012050. https://doi.org/10.1088/1742-6596/1832/1/012050

Ansumarwaty, F., Hikmawati, H., & Makhrus, M. (2023). Development of Student Worksheet for Sound Waves Based on Project Based Learning Model to Improve Students' Science Literacy. *Jurnal Penelitian Pendidikan IPA*, *9*(8), 6255-6264. http://dx.doi.org/10.29303/jppipa.v9i8.4651

Bassachs, M., Cañabate, D., Nogué, L., Serra, T., Bubnys, R., & Colomer, J. (2020). Fostering critical reflection in primary education through STEAM approaches. *Education sciences*, *10*(12), 384. http://dx.doi.org/10.3390/educsci10120384

Buhungo, T. J., Mustapa, D. A., & Arbie, A. (2021). Pengembagan perangkat pembelajaran team-based learning-inquiry pada pembelajaran daring berbantuan whatsapp dan zoom meeting pada materi gerak lurus. *Jurnal Pendidikan Fisika Dan Teknologi*, *7*(2), 147-152. http://dx.doi.org/10.29303/jpft.v7i2.3079

Cahyani, T. R., Prahani, B. K., & Admoko, S. (2023). The Effect of Problem Based Learning (PBL) Model on Students' Critical Thinking Ability in Sound Wave Material. *Studies in Philosophy of Science and Education*, *4*(3), 112-122. ttps://doi.org/10.46627/sipose.v4i3.281

Chairunnisa, N. A., Mursalin, M., & Ntobuo, N. E. (2022). Pengembangan Perangkat Pembelajaran Model Kolaboratif Jire Berbasis IT (Information and Technology) Materi Suhu dan Kalor Fisika. *Ideas: Jurnal Pendidikan, Sosial, dan Budaya*, *8*(3), 805-812. https://doi.org/10.32884/ideas.v8i3.712

Dewi, N. R., & Akhlis, I. (2016). Pengembangan Perangkat Pembelajaran IPA berbasis pendidikan Multikultural Menggunakan Permainan Untuk Mengembangkan Karakter Siswa. *Unnes Science Education Journal*, *5*(1). http://dx.doi.org/10.15294/usej.v5i1.9569

Facione, P. A. (2011). Critical thinking: What It Is And Why It Counts. *Insight assessment*, *1*(1), 1-23. Retrieved from https://www.insightassessment.com/wp-content/uploads/ia/pdf/whatwhy.pdf

Fuadi, H. (2023). The Effectiveness of PBL (Problem-Based Learning) Sound Wave Electronic Student Worksheets to Improve Critical Thinking Skills of High School Students. *2nd International Conference on Science Education and Sciences 2022 (ICSES 2022)*, 223-233. http://dx.doi.org/10.2991/978-94-6463-232-3_23

Guamanga, M. H., González, F. A., Saiz, C., & Rivas, S. F. (2023). Critical Thinking: The ARDESOS-DIAPROVE Program in Dialogue with the Inference to the Best and Only Explanation. *Journal of Intelligence*, *11*(12), 226. http://dx.doi.org/10.3390/jintelligence11120226

Habibah, F. N., Setiadi, D., Bahri, S., & Jamaluddin, J. (2022). Pengaruh Model Problem Based Learning berbasis Blended Learning terhadap Keterampilan Berpikir Kritis Peserta Didik Kelas XI di SMAN 2 Mataram. *Jurnal Ilmiah Profesi Pendidikan*, *7*(2b), 686-692. http://dx.doi.org/10.29303/jipp.v7i2b.603

Haddar, A. G., Hendriyanto, D., Munandar, H., Kelibia, M. U., & Muhammadiyah, M. U. (2023). Analysis of the Effectiveness of Project Steam-Based Learning Model to Improve Students'critical Thinking Skills. *Community Development Journal*, *4*, 10519-10525. Retrieved from https://repository.unibos.ac.id/xmlui/handle/123456789/9874

Hadis, E. S., Mursalin, M., & Paramata, D. D. (2022). Pengembangan Perangkat Pembelajaran IPA Menggunakan Model Discovery Learning Pada Materi Getaran dan Gelombang Untuk Meningkatkan Hasil Belajar Siswa di SMP. *Jambura Physics Journal*, *4*(1), 60-69. https://doi.org/10.34312/jpj.v4i1.12991

Hake, R. R. (1998). Interactive-Engagement Versus Traditional Methods: A Six-Thousand-Student Survey Of Mechanics Test Data For Introductory Physics Courses. *American journal of Physics*, *66*(1), 64-74. https://doi.org/10.1119/1.18809

Ismail, N. S., Harun, J., Zakaria, M. A. Z. M., & Salleh, S. M. (2018). The Effect Of Mobile Problem-Based

Learning Application Dicscience PBL On Students' Critical Thinking. *Thinking Skills and Creativity*, *28*, 177-195. https://doi.org/10.1016/j.tsc.2018.04.002

Khabibah, S. (2006). *Pengembangan Model Pembelajaran Matematika Dengan Soal Terbuka Untuk Meningkatkan Kreatifitas Siswa Sekolah Dasar*. Tesis, Surabaya: Pascasarjana Universitas Negeri Surabaya.

Kurnia, S. (2021). *Science, Technology, Engineering, Art, and Mathematics (STEAM) di Pendidikan Sains: Analisis Bibliometrik dan Pemetaan Literatur Penelitian Menggunakan Perangkat Lunak Vosviewer*. Doctoral dissertation, UIN Raden Intan Lampung. Retrieved from http://repository.radenintan.ac.id/14047/

Mabruroh, F., & Suhandi, A. (2017). Construction of critical thinking skills test instrument related the concept on sound wave. *Journal of Physics: Conference Series*, *812*(1), 012056. http://dx.doi.org/10.1088/1742-6596/812/1/012056

Marhamah, I., Yahdi, Y., & Hajaroh, S. (2020). Pengaruh model pembelajaran problem-based learning terhadap keterampilan berpikir kritis. *Spin Jurnal Kimia & Pendidikan Kimia*, *2*(1), 68-82. https://doi.org/10.20414/spin.v2i1.2012

Murti, K. (2015). *Pendidikan Abad 21 dan Aplikasinya Dalam Pembelajaran di SMK*. Jakarta: PT. Bumi Aksara.

Nagarajan, S., & Overton, T. (2019). Promoting systems thinking using project-and problem-based learning. *Journal of Chemical Education*, *96*(12), 2901-2909. https://doi.org/10.1021/acs.jchemed.9b00358

Nurhikmayati, I. (2019). Implementasi STEAM dalam pembelajaran matematika. *Jurnal Didactical Mathematics*, *1*(2), 41-50. http://dx.doi.org/10.31949/dmj.v1i2.1508

Rahayuni, G. (2016). Hubungan Keterampilan Berpikir Kritis Dan Literasi Sains Pada Pembelajaran IPA Terpadu Dengan Model PBM dan STM. *Jurnal penelitian dan Pembelajaran IPA*, *2*(2), 131-146. http://dx.doi.org/10.30870/jppi.v2i2.926

Ramdani, A., Jufri, A. W., Gunawan, G., Hadisaputra, S., & Zulkifli, L. (2019). Pengembangan alat evaluasi pembelajaran IPA yang mendukung keterampilan abad 21. *Jurnal Penelitian Pendidikan IPA*, *5*(1). http://dx.doi.org/10.29303/jppipa.v5i1.221

Putri, A. F. A., Utami, B., & Saputro, A. N. C. (2015). Penerapan model pembelajaran problem-based learning (PBL) disertai eksperimen untuk meningkatkan interaksi sosial dan prestasi belajar siswa pada materi pokok kelarutan dan hasil kali kelarutan di SMA Muhammadiyah 1 Karanganyar tahun pelajaran 2014/2015. *Jurnal Pendidikan Kimia*, *4*(4), 27-35. Retrieved from https://jurnal.fkip.uns.ac.id/index.php/kimia/article/view/6551

Putri, A. S., Prasetyo, Z. K., Purwastuti, L. A., Prodjosantoso, A. K., & Putranta, H. (2023). Effectiveness of STEAM-based blended learning on students' critical and creative thinking skills. *Int J Eval & Res Educ ISSN*, *2252*(8822), 8822. http://dx.doi.org/10.11591/ijere.v12i1.22506

Putri, R. K., Bukit, N., & Simanjuntak, M. P. (2021). The Effect of Project Based Learning Model's on Critical Thinking Skills, Creative Thinking Skills, Collaboration Skills, & Communication Skills (4C) Physics in Senior High School. *6th Annual International Seminar on Transformative Education and Educational Leadership (AISTEEL 2021)*, 323-330. Retrieved from https://www.atlantis-press.com/proceedings/aisteel-21/125962720

Rahmawati, Y., Ridwan, A., Hadinugrahaningsih, T., & Soeprijanto. (2019). Developing critical and creative thinking skills through STEAM integration in chemistry learning. *Journal of Physics: Conference Series,* 1156, 012033. http://dx.doi.org/10.1088/1742-6596/1156/1/012033

Sha, J., Shu, H., & Kan, Z. (2021). Analysis Of Critical Thinking Path Of College Students Under STEAM Course. *Frontiers in Psychology*, *12*, 723185. https://doi.org/10.3389/fpsyg.2021.723185

Suari, N. P. (2018). Penerapan Model Pembelajaran Problem-Based Learning Untuk Meningkatkan Motivasi Belajar IPA. *Jurnal Ilmiah Sekolah Dasar*, *2*(3), 241-247. https://doi.org/10.23887/jisd.v2i3.16138

Sugiyono. (2016). *Memahami Penelitian Kualitatif*. Bandung: Alfabeta

Sugiyono. (2019). *Metode Penelitian dan Pengembangan (R&D)*. Bandung: Alfabeta

Sukardi. (2013). *Metodologi Penelitian Pendidikan*. Yogyakarta: Bumi Aksara

Syukri, M., Ukhaira, Z., Herliana, F., & Arsad, N. M. (2022). The Influence of STEAM-Based Learning Application on Students' Critical Thinking Ability. *Asian Journal of Science Education*, *4*(2), 37-45. ttps://doi.org/10.24815/ajse.v4i2.28272

Utomo, W., Suryono, W., Jimmi, J., Santosa, T. A., & Agustina, I. (2023). The Effect of STEAM-Based Hybrid Based Learning Model on Students' Critical Thinking Skills. *Jurnal Penelitian Pendidikan IPA*, *9*(9), 742-750. http://dx.doi.org/10.29303/jppipa.v9i9.5147

Wilson, B., & Hawkins, B. (2019). Art and science in a transdisciplinary curriculum. *Circe Magazine: Steam Edition*, 27.

Zubaidah, S. (2019). STEAM (Science, Technology, Engineering, Arts, And Mathematics): Pembelajaran Untuk Memberdayakan Keterampilan Abad Ke-21. *Seminar Nasional Matematika Dan Sains, September*, 1-18.