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Development of STEM-Integrated Problem-Based Learning Instructional Materials to Enhance Science Students' Problem-Solving Ability

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Abstract: Mathematics education in Indonesia still faces challenges in developing students' Higher Order Thinking Skills (HOTS), particularly in mathematical problem-solving ability. One of the reasons for this is the limited availability of instructional materials specifically designed to support PBL-STEM. This study aims to develop Problem-Based Learning (PBL)-based mathematics instructional materials integrated with STEM to enhance the problem-solving abilities of science-stream students. This study is a Research and Development (R&D) project using the 4D model (Define, Design, Develop, and Disseminate). The subjects of this study consisted of 30 students from Grade 11 of SMAN 1 Labuhan Haji, who had low mathematical problem-solving skills. The developed materials included the Lesson Plan (RPP), Student Worksheet (LKS), problem-solving test, and practicality questionnaire for teachers. The results of validation by experts showed that the developed materials received an average score of 94.9%, which falls into the "highly valid" category. The practicality questionnaire, filled out by teachers, resulted in an average score of 92.5%, indicating that the materials are easy to use and well-structured. The effectiveness test, measured through a problem-solving test, showed an average N-Gain score of 0.72, which falls into the *"high"* category, indicating that the materials significantly improved students' problem-solving abilities. In conclusion, the PBL-STEM instructional materials developed in this study are valid, practical, and effective in enhancing the mathematical problem-solving ability of science-stream students.

Keywords: Instructional Materials; Mathematical Problem-Solving; Problem-Based Learning (PBL); Science Student; STEM

Introduction

The rapid advancement of science and technology in the 21st century has demanded a paradigm shift in education—from teacher-centred learning to student-centred learning that focuses on developing higher-order thinking skills (HOTS). One of the core cognitive abilities emphasised in modern mathematics education is problem-solving ability. This ability not only serves as a key indicator of students' success in understanding mathematical concepts but also functions as a prerequisite for cultivating critical, logical, and creative thinking patterns needed to face global challenges.

According to Rambe & Asmin, (2019), mathematical problem-solving ability is an essential competence that involves students' metacognitive awareness to plan, monitor, and evaluate strategies when dealing with problems. This process requires students not merely to memorise formulas but to construct knowledge through reflection and learning experiences. In the context of

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secondary school mathematics, problem-solving ability is closely related to students' mathematical thinking and scientific disposition (Delima, 2017). However, several studies have shown that this ability remains relatively low among Indonesian students. Such limitations are mainly caused by procedural learning that provides little opportunity for idea exploration and real-world application of concepts (Sumartini, 2018; Surya et al., 2016)

On the other hand, science-stream students—who are expected to possess strong analytical and experimental capabilities—require learning models that connect mathematical concepts with other scientific domains. One approach that aligns with this need is the Problem-Based Learning (PBL) model integrated with the Science, Technology, Engineering, and Mathematics (STEM) approach. PBL encourages students to learn through solving real-world problems, while the STEM approach strengthens interdisciplinary integration to build holistic and meaningful learning experiences.

Conceptually, PBL is a constructivist learning approach that positions students at the centre of the learning process. Students are confronted with complex, ill-structured problems that require them to explore, hypothesise, seek information, and test solutions collaboratively (Syawaluddin et al., 2019; Yuan et al., 2020). Thus, PBL develops not only cognitive skills but also learning responsibility and independence. Several studies have demonstrated that implementing PBL in mathematics education improves students' problem-solving ability, critical thinking, and positive attitudes towards mathematics (Ermayeni et al., 2020; Prastiti, 2020). Moreover, the collaborative environment fostered through PBL enables students to exchange ideas and enhance their mathematical communication skills(Rafli et al., 2018).

Nevertheless, the implementation of PBL in the context of science education becomes more meaningful when integrated with the STEM approach. STEM emphasises the interconnectedness of science, technology, engineering, and mathematics within a unified and contextual learning experience (Kelley & Knowles, 2016). Through this approach, students not only learn abstract concepts but also understand their application in real life through project- and experiment-based learning. (Nelson et al., 2018) argue that STEM education plays a pivotal role in preparing students for 21st-century challenges by nurturing creativity, collaboration, and systematic thinking. Other studies have confirmed that STEM-based learning significantly enhances problem-solving abilities and fosters positive attitudes towards science (Buckley et al., 2018; Kurt & Benzer, 2020).

The integration of PBL with STEM—commonly referred to as PBL-STEM—creates a more authentic and meaningful learning approach. PBL provides a structured problem-solving framework, whereas STEM offers an interdisciplinary context that enriches students' thinking processes. Studies by Rosli et al., (2019) and Priemer et al., (2019) indicate that PBL-STEM implementation significantly improves students' analytical, evaluative, and reflective skills. This improvement occurs because students are encouraged to solve contextual problems through cross-disciplinary collaboration and relevant technological applications. Consequently, the integration of these two approaches makes mathematics learning more applicable, project-oriented, and aligned with real-world demands.

In the context of mathematics learning within science departments, implementing the PBL-STEM model is highly relevant, as it bridges mathematical concepts with natural and technological phenomena studied by students. For example, the topic of "circles" can be linked to circular motion in physics, cell structure in biology, or rotating mechanical components in engineering. Through such activities, students not only master geometric concepts theoretically but are also able to apply them to real-life problems in scientific contexts. Hence, mathematics learning no longer stands alone but becomes an integrative medium that fosters cross-disciplinary thinking and innovative capability.

Previous studies have shown that the PBL model effectively enhances critical thinking and mathematical problem-solving skills (Ermayeni et al., 2020; Sumartini, 2018), while the STEM approach strengthens collaboration, creativity, and analytical thinking through interdisciplinary activities (Kurt & Benzer, 2020; Rosli et al., 2019). However, most of these studies examined PBL or STEM separately, without integrating the two into a concrete and measurable instructional design. Moreover, many teachers remain focused solely on achieving cognitive outcomes and have yet to harness the potential of interdisciplinary learning to enhance students' higher-order thinking skills (Astuti et al., 2021; Winarno & Maulana, 2020). Therefore, this study offers novelty by conceptually and practically integrating PBL and STEM in developing mathematics instructional materials, which are expected not only to enhance students' problem-solving ability but also to nurture scientific and applied ways of thinking in line with 21st-century educational demands. Furthermore, the limited availability of learning materials specifically designed to support PBL-STEM remains a challenge. Thus, it is essential to develop STEM-integrated PBL instructional materials that are valid, practical, and effective in improving science students' mathematical problem-solving abilities.

Such instructional materials are expected to accommodate the analytical and experimental characteristics of science students by providing activities

That require the application of mathematical concepts in scientific and technological contexts. In addition, this approach fosters essential 21st-century skills such as collaboration, creativity, critical thinking, and scientific communication—competencies that are indispensable in the digital era. Through learning that emphasises real-world problem-solving and interdisciplinary integration, students are expected not only to solve mathematical problems algorithmically but also to comprehend their meaning and applications in real-life and professional scientific contexts.

In conclusion, this study holds significant urgency. The development of PBL-STEM-based instructional materials represents a strategic step towards addressing the need for pedagogical innovation in mathematics education, particularly for science students. The resulting product is expected to serve as a model of learning that can be adapted by teachers across various mathematical topics to enhance problem-solving ability while preparing a generation of competent, adaptive, and globally competitive learners.

Method

This study employed a Research and Development (R&D) design with the aim of producing mathematics instructional materials based on the Problem-Based Learning (PBL) model integrated with STEM that are valid, practical, and effective in enhancing the problem-solving ability of science-stream students. The development procedure adopted the 4D model (Define, Design, Develop, and Disseminate) proposed by Thiagarajan, Semmel, and Semmel. This model was selected because it provides systematic steps for designing and validating educational products, from needs analysis to product dissemination (Firmansyah, 2019; Krismadinata et al., 2019; Ristanto, 2020). The flow of the research procedure is illustrated in Figure 1. Based on Figure 1, the research procedure consisted of four stages—Define, Design, Develop, and Disseminate.

The Define stage aimed to identify the needs for developing instructional materials appropriate to the characteristics of science students. The analysis involved four main activities: (1) Preliminary and final analysis, to identify issues in mathematics learning that remain procedural and have not yet developed higher-order thinking skills; (2) Learner analysis, focusing on learning styles, interest in science, and logical as well as analytical thinking abilities; (3) Concept analysis, to determine mathematical topics with potential for integration into STEM contexts; and (4) Learning objective analysis, formulating learning outcomes that emphasise problem-solving abilities and cross-disciplinary concept application.

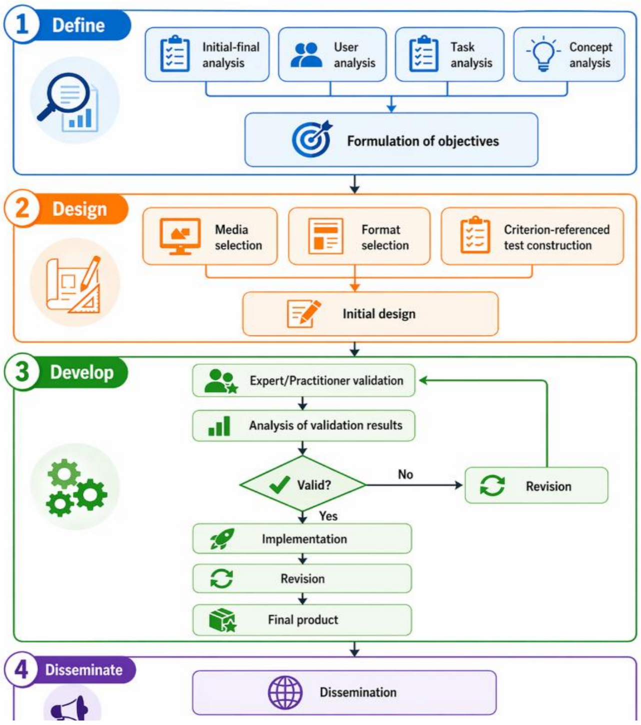

Figure 1. Research Procedure

The results of this stage served as the foundation for designing contextual PBL-STEM learning materials oriented towards 21st-century competencies (Rahayu & Mulyatiningsih, 2019). The Design stage involved developing the initial drafts of the learning materials, which included: (a) Lesson Plans (RPP) based on the PBL-STEM framework, (b) Student Worksheets (LKPD) integrating problem-based and project-based STEM activities, (c) an assessment instrument for measuring problem-solving ability, and (d) validation sheets and practicality questionnaires. The design integrated the syntax of the PBL model with the STEM approach (Science, Technology, Engineering, and Mathematics) in a structured manner. Each learning activity was designed to stimulate students' ability to analyse contextual problems and apply mathematical concepts in real-world situations.

The Develop stage consisted of creating, validating, and testing the instructional materials. Validation was conducted by two experts—one in mathematics content and one in education. The effectiveness of the product was measured by analysing improvements in students' mathematical problem-solving abilities, adapted from Polya's indicators: understanding the problem, planning a strategy, implementing the solution, and evaluating the results (Fitria et al., 2020; Setyawati et al., 2020).

The Disseminate stage aimed to distribute the validated learning materials through dissemination activities such as workshops with mathematics teachers from partner schools, academic seminars, and journal publications. The goal was to ensure broader utilisation and adaptation of the developed materials in other mathematics learning contexts. The dissemination process also included collecting feedback from educational practitioners for continuous improvement (Firmansyah, 2019).

The subjects of this study were Year 11 science-stream students from SMA Negeri 1 Labuhan Haji. The sample was selected using a purposive sampling technique, involving one class of 30 students. The selection was based on the consideration that these students demonstrated relatively low problem-solving abilities and required contextual learning approaches to improve their mathematical problem-solving skills.

The research employed several instruments designed to comprehensively measure the validity, practicality, and effectiveness of the developed product. The main instruments included: (1) Validation sheets for evaluating the content feasibility, alignment with learning objectives, accuracy of mathematical concepts, and coherence of PBL-STEM syntax; (2) Teacher response questionnaires to assess the practicality of the materials in terms of ease of use, clarity of learning steps, and relevance to classroom conditions; and (3) Mathematical problem-solving tests, developed based on Polya's indicators, assessing students' ability to understand problems, plan strategies, execute procedures, and evaluate results. Additionally, a semi-structured interview guide was used to collect qualitative data regarding teachers' experiences in implementing the materials. All instruments were validated by experts to ensure clarity, content relevance, and measurability of indicators, thereby ensuring high reliability of the data collected in assessing the quality of the developed instructional materials.

Data analysis employed both quantitative and qualitative approaches in line with the study's objectives, focusing on evaluating the validity, practicality, and effectiveness of the developed learning materials. The quantitative analysis was used to process expert validation scores, teacher and student responses, and test results on problem-solving ability. Meanwhile, the qualitative analysis was used to describe responses, experiences, and challenges encountered during the implementation of the instructional materials in the classroom.

The validity analysis was conducted by calculating the average scores provided by two validators—experts in content, pedagogy, and media. Each aspect was rated using a five-point Likert scale, and the resulting data were converted into percentage scores using Formula 1

$$Validity\ persentage\ (\%) = \frac{Total\ scor\ obtined}{Maximum\ possible\ scor}\ x\ 100\% \quad (1)$$

The results of the calculations are interpreted into the following validity categories at Table 1.

Table 1. Validity Criteria for Learning Tools

Interval percentage	Validity Criteria
80% < Scor ≤ 100%	Very valid
60% < Scor ≤ 80%	Valid
40% < Scor ≤ 60%	Fairly valid
20% < Scor ≤ 40%	Less valid
0% < Scor ≤ 20%	Not Valid at All

The instructional materials were considered feasible for use if they obtained a validity rating categorised as valid or highly valid.

The practicality analysis of the instructional materials was conducted using data obtained from teacher questionnaires administered after the classroom implementation. Practicality was measured based on several criteria, including ease of use, clarity of instructions, appropriateness of implementation time, and usefulness for the learning process. The data were analysed by calculating the average percentage score of responses, which was then classified into five levels of practicality as presented in the following Table 2.

Table 2. Practicality Criteria for Learning Tools

Percentage	Practically Criteria
80%< Scor ≤100%	Very practical
60%< Scor ≤80%	Practical
40%< Scor ≤60%	Fairly Practical
20%< Scor ≤40%	Less Practical
0%< Scor ≤20%	Not Practical at all

In addition to quantitative data, the teacher interview results were also analysed descriptively to strengthen the findings of the practicality assessment, particularly in identifying the strengths and limitations of the developed instructional materials.

The effectiveness analysis of the instructional materials was conducted using students' pre-test and post-test scores on mathematical problem-solving ability. The obtained scores were analysed using the N-Gain formula to determine the magnitude of improvement in students' abilities before and after the implementation of the learning process.

Furthermore, the effectiveness of the instructional materials in improving students' mathematical problem-solving ability was measured using the N-Gain test, calculated with Formula 2.

$$N - \text{Gain} = \frac{Posttest\ Scor - Pretest\ Scor}{Ideal\ Scor - Pretest\ Scor} \quad (2)$$

To assess the category of the N-Gain score improvement, one can refer to the normalized Gain criteria in Table 3.

Table 3. Criteria for N-Gain (g) Categorization

Scor Interval	Category
0,7 ≤ g	High
0,3 ≤ g < 0,7	Medium
g < 0,3	Low
g=0	No increase has occurred.
-1,00 ≤ g < 0,00	A decrease has occurred

In addition, qualitative data obtained from classroom observations and interviews were used to complement the quantitative analysis. The purpose was to identify the factors influencing the implementation of learning activities, students' learning motivation, and teachers' perceptions of the usefulness of the instructional materials. This analysis provided a comprehensive overview of how the developed PBL-STEM instructional materials contributed to enhancing students' mathematical problem-solving abilities in a realistic and contextual manner.

Result and Discussion

This study was conducted to produce a set of mathematics instructional materials based on the Problem-Based Learning (PBL) model integrated with STEM, which are valid, practical, and effective in improving the mathematical problem-solving ability of science-stream students.

The developed instructional materials consisted of the Lesson Plan (RPP), Student Worksheet (LKPD), Practicality Questionnaire, and Mathematical Problem-Solving Test Sheet.

Samples of the developed instructional materials are presented in Figures 2 and 3 below.

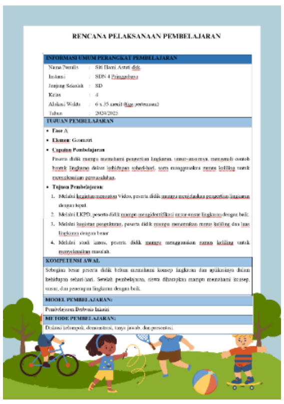

Figure 2. Screenshot of the Lesson Plan (RPP) Design

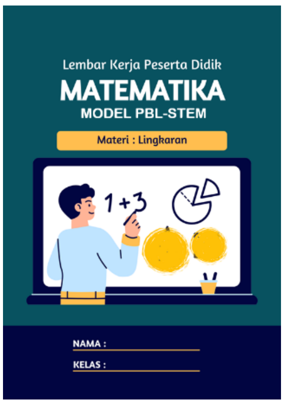

Figure 3. Screenshot of the Student Worksheet (LKPD)

The product developed in this study is a STEM-integrated instructional material based on Problem-Based Learning for the mathematics topic of circles. The material was designed to help students understand the fundamental concepts of circles while applying them to contextual problem-solving situations. The content covers the elements of a circle, the relationship between radius and diameter, circumference, area, and the application of circle concepts in everyday contexts. Therefore, the instructional material is intended not only to deliver mathematical content but also to engage students in meaningful and systematic problem-solving activities.

The developed product consists of several main components, including content explanations, problem-based learning activities, student worksheets, problem-solving exercises, and assessment instruments. The learning process begins with contextual problems related to real-life circular objects, such as wheels, clocks, circular gardens, and other everyday examples. These problems serve as triggers for students to connect mathematical concepts with authentic situations. Students are then guided to identify the problem, gather relevant information, discuss possible solutions, and draw conclusions based on their analysis.

STEM integration is explicitly embedded in the instructional design. The science aspect is reflected in students' observation of real objects and phenomena related to circular forms in their surroundings. The technology aspect is incorporated through the use of digital media or geometry applications to support concept visualization. The engineering aspect is represented in design-oriented tasks that require students to propose or evaluate solutions to real-world problems involving circular objects. Meanwhile, the mathematics aspect serves as the core component, particularly in the use of formulas, mathematical reasoning, symbolic representation, and interpretation of results. Through this integration, the developed instructional material is expected to provide a more meaningful, contextual, and interdisciplinary learning experience while enhancing students' problem-solving ability.

Each instructional component was systematically evaluated through expert validation, limited classroom trials, and analysis of teacher and student responses. A comprehensive overview of the testing results of the PBL-STEM instructional materials, as a pedagogical innovation with the potential to enhance students' mathematical problem-solving ability, is presented as follows.

Validation Results of the Instructional Materials

The validation of the STEM-integrated Problem-Based Learning (PBL) instructional materials was carried out by two validators: a mathematics content expert and an education expert. The validated instruments comprised four main components: (1) the Lesson Plan (RPP), (2) the Student Worksheet (LKPD),

(3) the Teacher Response Questionnaire, and (4) the Mathematical Problem-Solving Test Sheet.

The results of the validation process for these instruments are presented in Table 4.

Table 4. Validation Results of the Instructional Instruments

Instrument	Average Score	Max Score	Percentage	Criteria
Lesson Plan	92	96	95.83%	Very Valid
Student Worksheet	68.5	72	95.14%	Very Valid
Teacher Response Questionnaire	56	60	93.33%	Very Valid
Mathematics Problem Solving Ability test	61	64	95.31%	Very Valid

Based on the validation results presented in Table 4, the percentage of validity obtained was 95.83% for the Lesson Plan (RPP), 95.14% for the Student Worksheet (LKPD), 93.33% for the Teacher Response Questionnaire, and 95.31% for the Mathematical Problem-Solving Test Sheet. The overall average validity score reached 94.9%, which falls into the "highly valid" category.

These results indicate that the developed instructional materials met the criteria for content feasibility, alignment with learning objectives, and integration with the syntax of the PBL model and the STEM approach. The high validation scores also demonstrate that each component of the instructional materials possesses a logical structure, communicative language, and content relevant to the characteristics of science students. Conceptually, the structure and content of the instructional materials fulfilled the fundamental principles of student-centred innovative learning.

The validators confirmed that each component of the materials showed consistency among learning objectives, content, activities, and assessment, as well as coherence with the PBL syntax integrated with STEM. These findings align with (Mustaffa et al., 2016), who asserted that the success of PBL implementation largely depends on the clarity of learning stages and the relevance of the problems presented. In this study, contextual problems were presented through an interdisciplinary approach that connected concepts from mathematics, science, technology, and engineering, allowing students to perceive the interrelationships among these domains.

According to (Prastiti, 2020), the design of learning materials that embed real-world contexts can enhance the constructivist validity of mathematics learning, as it provides meaningful connections between abstract concepts and students' experiences.

Furthermore, from a content perspective, the materials were deemed valid because they adhered to the principles of PBL development, which emphasise inquiry, collaboration, and reflection (Peranginangin et al., 2019). This finding demonstrates that the validation process not only ensured document completeness but also examined the alignment between learning theory, instructional model, and cognitive goals—namely, the improvement of students' mathematical problem-solving abilities.

Therefore, the developed instructional materials were declared feasible for implementation in the practicality and effectiveness testing stages.

Results of the Practicality Test

The practicality of the instructional materials was evaluated based on the teacher response questionnaire administered after classroom implementation. The assessed aspects included the ease of use, clarity of activity steps, coherence between learning activities and objectives, and the realism of time allocation.

Based on the data analysis, the average teacher response score was 92.5%. Teachers stated that the instructional materials were easy to use, systematic, and effective in facilitating problem-based learning activities that challenge students to think critically.

This high level of practicality indicates that the developed PBL-STEM instructional materials are not only feasible for classroom implementation but also effectively promote active student engagement throughout the learning process.

To gain deeper insight into the practicality of the developed instructional materials, interviews were conducted with the teacher who implemented the materials in the classroom. The purpose of the interviews was to explore the teacher's direct experiences in using the STEM-integrated Problem-Based Learning (PBL) materials and to identify aspects that facilitated or possibly hindered the teaching process. Excerpts from the teacher interview are presented in the following dialogue.

Researcher : *In general, how would you assess the practicality of the instructional materials that were developed?*

Teacher : *In my opinion, these instructional materials are very practical and ready to be used in the classroom. All components—the lesson plan, student worksheet, and assessment instruments—are well-organised and easy to follow. The Problem-Based Learning syntax is clearly described, so I did not need to make many adjustments during teaching. I could simply* *follow the sequence of activities provided, and everything ran according to the allocated time.*

Researcher: *Did the materials make it easier for you to organise students' learning activities?*

Teacher : *Yes, absolutely. The worksheets contain systematic and well-directed activity guides. Each student group already knows what to do at each stage of the PBL process—from understanding the problem, conducting an investigation, to presenting their results. The instructions are concise, clear, and easily understood by students without additional explanation. For teachers, this is very helpful because it makes classroom time more efficient.*

Researcher : *How about the clarity of language and the visual design of the materials?*

Teacher : *In terms of appearance and language, the materials are also very practical. The design is simple yet appealing, and the language used is easy for students to understand. The illustrations in the worksheets help students grasp the concepts more quickly, especially when discussing the relationships between radius, diameter, and circumference.*

Researcher : *Does the integration of STEM within these materials also support the practicality of classroom implementation in the science stream?*

Teacher : *It does, very much so. The STEM-based activities in these materials do not require complicated tools. For example, when students calculate the rotational speed of a wheel or design a simple water turbine model, the materials can easily be found around the school. Such activities are highly suitable for science students, as they can directly see the application of mathematical concepts in scientific, technological, and engineering contexts.*

Researcher : *During the learning process, did you encounter any challenges in using these materials?*

Teacher : *The main challenge was time management. Since PBL-STEM activities require students to be actively involved in discussions and investigations, some groups occasionally needed more time during the inquiry and presentation stages. However, this challenge can be addressed by tightening discussion time and providing clearer guidance at the beginning of the lesson. Overall, the challenges were relatively minor compared to the benefits gained.*

Researcher : *What suggestions would you give to improve these materials in the future?*

Teacher : *I suggest that these instructional materials be expanded to include other mathematics topics as well. This would greatly help new teachers who are not yet familiar with the PBL-STEM model. Overall, these materials are highly practical, comprehensive, and very suitable for developing students' mathematical problem-solving skills, particularly in science classes.*

The results of the interview support the findings regarding the practicality of the developed instructional materials. The teacher stated that the materials were highly helpful for classroom management, as each stage of the learning process was accompanied by clear and structured guidance. The Student Worksheet (LKPD) included discussion instructions, thought-provoking questions, and exploratory activities relevant to the science context, such as measuring the linear speed of a wheel, simulating circular motion, or designing a miniature turbine disc model.

These findings indicate that the integration of STEM within the materials not only enriched the content but also enhanced the practicality of implementation, as the activities could be conducted using simple tools and materials available in the surrounding environment (Hakim et al., 2019).

Another strength of the instructional materials lies in their visual presentation and communicative language, which made it easier for students to understand their tasks. According to the teacher, the inclusion of a reflection guide at the end of the worksheet was particularly useful in evaluating students' thinking processes without the need for additional sheets.

This level of practicality aligns with the findings of (Hidayati & Wagiran, 2020), who emphasised that an effective PBL instructional material should be simple, easy to understand, and capable of guiding students independently through investigative learning activities.

Result Effectiveness Test of the Instructional Materials

The effectiveness of the instructional materials was measured based on the improvement of students' mathematical problem-solving ability, as indicated by the results of the pre-test and post-test. The data were analysed using the N-Gain score formula to determine the extent of improvement in students' learning outcomes after the implementation of the PBL-STEM instructional materials.

Furthermore, based on the results of the N-Gain analysis processed using SPSS software, the findings are presented in Table 5 .

Table 5. Result of N-Gain Test

	N	Minimum	Maximum	Mean	Std. Deviation
NGain	30	.00	1.00	.7166	.25572
NGain_persen	30	.00	100.00	71.6555	25.57205
Valid N (listwise)	30				

Based on Table 5, it was found that the average N-Gain score was 0.72, which falls within the "high" category. In addition, 83% of students achieved scores above the minimum mastery criterion (70), indicating that the developed instructional materials were effective in improving students' understanding and mathematical problem-solving ability.

Qualitative observations further revealed that students became more active in discussing ideas, were able to connect mathematical concepts with scientific phenomena, and demonstrated improvement in all stages of Polya's problem-solving process—from understanding the problem to evaluating the solution.

These findings reinforce previous research (Fitria et al., 2020; Sumartini, 2018), which concluded that the Problem-Based Learning (PBL) model enhances students' critical thinking and problem-solving abilities. In the context of the present study, the integration of PBL with the STEM approach further extended the learning impact by providing a more authentic interdisciplinary context.

Based on the results described above, it can be concluded that the STEM-integrated PBL-based instructional materials developed in this study are valid, practical, and effective in improving the mathematical problem-solving ability of science-stream students. These findings are consistent with various prior studies that have affirmed the integration of PBL and STEM as an effective strategy for developing students' mathematical problem-solving skills (Hakim et al., 2019; Peranginangin et al., 2019; Ulandari et al., 2019).

The Problem-Based Learning (PBL) approach has long been recognised as an effective instructional model for developing students' problem-solving abilities. PBL positions students as the centre of the learning process, focusing on solving real-world problems that demand the use of critical, analytical, and creative thinking skills. In the context of mathematics education, PBL encourages students not only to understand theories but also to apply mathematical concepts to situations relevant to everyday life.

This is in line with (Prastiti, 2020), who found that PBL enhances problem-solving ability because students are actively involved in identifying problems, gathering information, and formulating solutions either individually or collaboratively. Each stage of PBL—from problem orientation and analysis to solution development and evaluation—fosters higher-order thinking skills, which are essential for mathematical problem-solving.

Such an approach is highly relevant in mathematics learning, where students often face problems that require analytical reasoning, strategic planning, and solution testing. Thus, the integration of PBL with STEM not only strengthens conceptual understanding but also cultivates interdisciplinary thinking and authentic problem-solving competencies among science students.

Furthermore, Problem-Based Learning (PBL) promotes active student engagement, which, according to (Mustaffa et al., 2016), enhances students' mastery of the material as they feel more responsible for their own learning process. This active involvement helps students develop metacognitive skills—the ability to plan, monitor, and evaluate the strategies they use in solving mathematical problems—thereby improving the quality of their problem-solving performance.

While PBL provides a structured framework for problem-solving, the integration of STEM (Science, Technology, Engineering, and Mathematics) within mathematics education enriches both the context and application of mathematical concepts. In STEM learning, mathematics is not taught as an abstract set of ideas but rather as a tool for solving real-world problems in science, technology, and engineering. This aligns with (Hakim et al., 2019), who stated that STEM-based learning enhances students' applied understanding of mathematics, enabling them to use mathematical concepts to address problems arising in scientific and technological contexts.

The integration of STEM within PBL also introduces a project-based learning approach that motivates students to develop creative and innovative solutions to the problems presented. For instance, when students are tasked with calculating the circumference of a circle in the context of designing a miniature water turbine, they not only learn mathematical formulas but also apply engineering and technological skills to construct simple models or prototypes. This makes mathematics learning more relevant and authentic, while simultaneously improving students' problem-solving abilities, as they engage with real-world challenges requiring cross-disciplinary collaboration.

Research by (Ulandari et al., 2019) demonstrated that the STEM approach within PBL helps students develop critical and analytical thinking skills essential for mathematical problem-solving. This integration encourages students not only to understand mathematical procedures but also to see how mathematical concepts function in practical applications, particularly in technological and engineering contexts.

This study has several limitations that should be acknowledged. First, the developed instructional materials were limited to the topic of circles, so the findings cannot be directly generalized to other mathematics topics with different conceptual characteristics. Second, the study involved participants from a limited educational context, which may restrict the broader generalizability of the results. Third, the implementation period was relatively short, so the long-term impact of the instructional materials on students' problem-solving ability could not be fully examined. In addition, the study primarily focused on problem-solving ability and did not explore other potential outcomes, such as creativity, mathematical communication, or students' attitudes toward learning. Therefore, future research is recommended to apply similar instructional materials to other mathematical topics, involve more diverse participants, extend the duration of implementation, and examine a wider range of learning outcomes.

Several advantages emerge from the implementation of PBL-STEM in mathematics learning: (1) PBL-STEM enhances student engagement and motivation. Learning that integrates real-world contexts—such as design and technology— increases students' interest in mathematics. This is significant because high motivation is directly associated with greater effort and persistence in solving mathematical problems (Berkowitz & Stern, 2018). Students become more engaged when they see the direct relevance of mathematics to everyday life, thereby strengthening their intrinsic motivation to learn. (2) PBL-STEM stimulates the development of collaboration skills. The project-based nature of PBL-STEM requires students to work collaboratively, which enhances their communication and teamwork abilities. Within groups, students share ideas and problem-solving strategies, which deepens understanding and improves their capacity for critical thinking (Prastiti, 2020); Setiawan et al., 2020). (3) PBL-STEM improves mathematical problem-solving ability. PBL-STEM encourages students to develop creative solutions to the problems they encounter. Rather than relying solely on established techniques or formulas, they are prompted to experiment, test, and discover new approaches—thus strengthening their mathematical problem-solving competence (Fahmi et al., 2019). (4) PBL-STEM fosters interdisciplinary knowledge application. In PBL-STEM learning, students not only study mathematics but also apply knowledge from science, technology, and engineering to address complex problems. This enhances students' understanding of the interconnectedness between disciplines and prepares them to face real-world challenges that demand multidisciplinary knowledge (Hakim et al., 2019; Indah Nuurjannah & Sayoga, 2020).

Conclusion

Based on the results of data analysis and the discussion presented, it can be concluded that the STEM-integrated Problem-Based Learning (PBL) instructional materials developed in this study are valid, practical, and effective for enhancing the problem-solving ability of science-stream students in Year 11 at SMA Negeri 1 Labuhan Haji. Based on the findings of this study, several recommendations can be proposed to ensure that the results can be implemented effectively and sustainably.

First, for mathematics teachers, the developed instructional materials can be used as an innovative alternative in implementing learning activities oriented towards the development of higher-order thinking skills (HOTS), particularly problem-solving ability. Through the application of the STEM-integrated Problem-Based Learning (PBL) model, teachers can create a more challenging, contextual, and collaborative learning process in which students not only understand concepts theoretically but are also able to connect science, technology, engineering, and mathematics in solving real-world problems. Teachers are also encouraged to adapt the contextual problems presented in the materials to the local potential and students' everyday experiences, so that learning activities become more relevant and meaningful.

Second, for schools, the results of this study can serve as a reference for expanding the implementation of the STEM-integrated PBL model to other subjects related to science and technology. In doing so, schools can cultivate a learning culture that promotes 21st-century skills, such as critical thinking, creativity, collaboration, and communication. Furthermore, school support in providing STEM-related learning facilities—for example, simple experimental tools, digital devices, or project materials—will be highly beneficial in optimising the success of the implementation of these instructional materials.

Third, for future researchers, this study can be further developed by involving a larger sample size and a longer trial period to obtain more comprehensive and generalisable results. Future studies may also focus on examining the impact of the STEM-integrated PBL model on other aspects such as creativity, collaboration skills, and students' STEM literacy, as well as exploring its application in digital or project-based STEM learning contexts.

Thus, the findings of this research are expected to serve as an initial foundation for the broader development of innovative STEM education, particularly in science and mathematics learning, contributing to the improvement of science education quality.

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