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Enhancing Students' Mathematical Representation and Learning Motivation through Problem-Based Learning Worksheets in the Sound Wave Topic

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Abstract: This study aims to examine the implementation of student worksheets based on the problem-based learning model to enhance students' mathematical representation skills and learning motivation in the topic of sound waves. Problem-based learning (PBL) makes the study of sound waves more engaging for students by emphasizing the comprehension of ideas and their application in the real world, rather than memorizing formulas. The research was conducted in Class XI of SMA Negeri 1 Godean, Yogyakarta, involving 33 students, using a quantitative approach and a pre-experimental design in the form of a one-group pretest-posttest design. The instruments used were a mathematical representation ability test and a learning motivation questionnaire. The data analysis results showed an increase in the average post-test scores compared to the pre-test. Based on the paired sample t-test, students' mathematical representation skills showed a statistically significant improvement ($p < 0.001$) with an N-gain score of 0.68, resulting in an increase in scores from 51 to 85. This result is supported by the effectiveness test using Cohen's d, which indicated a very large effect size ($d = 2.35$). Meanwhile, students' learning motivation showed a statistically non-significant increase (sig. = 0.055 > 0.05), with an N-gain score of 0.038 and a slight increase in scores from 48 to 50. Cohen's d effect size test for learning motivation fell into the small effect category ($d = 0.32$). Although not statistically significant, there was an indication of improved student learning outcomes after the intervention, as reflected in the mean score differences. These results show that problem-based learning models integrated into student worksheets are highly effective in enhancing students' mathematical representation abilities and raising their motivation to learn. Therefore, the implementation of problem-based learning student worksheets can serve as an effective alternative instructional strategy in physics education, particularly in improving students' cognitive aspects. Further research with a more extended implementation period and a more comprehensive approach is recommended to optimize the impact on affective aspects.

Keywords: problem-based learning, student worksheet, mathematical representation, learning motivation, sound waves.

▪ INTRODUCTION

Twenty-first-century learning, often referred to as the era of the Industrial Revolution 4.0, requires students to possess a wide range of skills and competencies. According to national and international standards, one of the key indicators of success in 21st-century education is the presence of problem-solving abilities in every stage of the learning process (Puspa et al., 2023). According to the World Economic Forum's Future of Jobs report, problem-solving is identified as one of the top skills most needed in the future (Thornhill-Miller et al., 2023). In order for students to be prepared for the future workplace, Trilling & Fadel (2009) state that teachers must teach them modern skills such as innovation, creativity, collaboration, critical thinking, problem-solving, and communication. Teachers play an important role in fostering students' knowledge, abilities, and attitudes. Therefore, teaching strategies that engage students, encourage

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them to communicate spontaneously and effectively, and help them acquire skills relevant to the 21st century are essential (Suwastini et al., 2021). Therefore, students must be equipped from an early age to develop a competitive advantage in facing the ever-evolving global challenges.

The Indonesian government introduced the Merdeka Curriculum as an educational reform aimed at addressing current global challenges. The Merdeka Curriculum emphasizes student-centered learning, flexibility in content delivery, and greater autonomy for teachers in designing learning experiences (Nurdiyanti et al., 2024). This curriculum is designed to foster critical thinking, creativity, collaboration, and communication skills that align with the demands of 21st-century education. Several learning strategies can be employed to implement the Merdeka Curriculum, including Problem-Based Learning, Discovery Learning, Inquiry-Based Learning, and Scientific Learning (Dewi, 2022). The learning process becomes more pertinent and meaningful because of this active learning model that lets students take responsibility for what they learn and work together (Silitubun et al., 2024). The application of learning models that align with students' needs is crucial for achieving the goals set by the Merdeka Curriculum.

Physics education plays a vital role in shaping students' understanding of the natural phenomena occurring around them. However, physics learning is often perceived as abstract and difficult to comprehend by students, as it tends to emphasize conceptual mastery without active student engagement in solving contextual problems (Permatasari et al., 2018). Problem-based learning has been identified as an effective approach for improving conceptual understanding, problem-solving skills, and learning motivation by using authentic problems as a trigger for discussion and scientific exploration (Putra & Iswantir, 2021; Muahor & Yulianto, 2023). Problem-based learning supports and encourages students to develop critical, creative, and analytical thinking skills necessary for solving complex problems (Meke et al., 2019) . Aligned with the Merdeka Curriculum, this model is designed to cultivate various 21st-century competencies. Through problem-based learning, students become accustomed to learning from real and factual problems in everyday life, engaging in group work and discussions to explore issues, seeking relevant information, gathering data, evaluating alternative solutions, and formulating their own problem-solving strategies (Mann et al., 2021).

Sound waves are a crucial topic in physics that Grade 11 students must understand. Under the current curriculum, namely the Merdeka Curriculum, students are expected to apply the concepts and principles of sound waves to solve real-life problems. Sound waves are a topic that is well-suited for training mathematical representation because of their periodic and sinusoidal nature, which enables precise modeling using trigonometric functions and clear quantitative relationships between physical quantities (Doyan et al., 2021). By describing sound waves in a variety of methods, such as equations or graphs, students will improve their modeling abilities and get a greater understanding of physical processes. This topic requires students to construct their knowledge through independent problem-solving. Therefore, an appropriate learning method is needed—one that prioritizes student-centered learning, encourages active and independent participation, and fosters critical thinking skills.

A field study conducted in Class XI at SMA Negeri 1 Godean, Yogyakarta, revealed that the learning process remains teacher-centered. As a result, students tend to receive information directly from the teacher rather than discovering and constructing knowledge independently and actively. Consequently, students' thinking skills are not adequately developed, leading to low learning outcomes. Based on observations and interviews with teachers, it was found that students generally have low mathematical representation skills, which in turn affects their learning motivation and ultimately leads to decreased academic performance. Due to a lack of interest in learning physics, Indonesian students often struggle with mathematical representations of sound wave content. The perceived abstract nature of physics and non-interactive teaching strategies make students think the subject is complex and dull, which prevents them from mastering a deep mathematical representation (Doyan et al., 2021; Mirsa et al., 2023). As a result, students often memorize formulas without understanding the concepts or being able to replicate physical phenomena (Djudin, 2023). This presents a challenge for teachers to design learning experiences that actively engage students and stimulate their interest and creativity.

In the context of education, mathematical representation skills are among the essential competencies that students must develop in order to understand and apply concepts, particularly in physics learning (Alvarez-Garreton et al., 2018). In problem-solving processes, mathematical representation is one of the most commonly used tools in physics instruction (Fatmaryanti et al., 2017). Research involving multi-representational learning models combined with problem-based learning has shown significant improvements in students' representational skills, where students were able to shift effectively between various modes of representation (graphical, mathematical, and verbal) (Rasyid et al., 2025). Mathematical representation includes the use of symbols, graphs, and mathematical models to describe relationships between physical variables. One development-based study on multi-representational approaches demonstrated both the validity and effectiveness of improving students' mathematical representation skills (Fatmawati & Shofiyah, 2022).

Students with strong mathematical representation skills are better equipped to solve complex and challenging physics problems. Unfortunately, mathematical representation ability in the field of physics remains relatively low (Badmus & Jita, 2022). Many students struggle with learning physics due to a lack of understanding in applying mathematical concepts to solve physics problems (Wilujeng & Hidayatullah, 2021). Learners who possess good representational skills are more likely to understand the material with ease. Therefore, developing students' mathematical representation abilities must be a key consideration in designing effective physics instruction.

In addition to representational ability, learning motivation is often a major challenge in physics education. The problem-based learning model promotes collaborative and reflective learning, which has been shown to enhance students' motivation (Murdani et al., 2022; Wulandari et al., 2023). Research findings indicate that PBL is highly effective in improving logical thinking skills and motivation, especially when combined with innovative learning media such as student worksheets (Sagala et al., 2023). Several studies have demonstrated that the application of problem-based learning in physics instruction results in significantly higher student motivation compared to traditional methods (Lee et al., 2023).

The appropriate selection of learning media encourages students to become more active and motivated in the learning process, making it easier for them to absorb the lesson content. Learning media, in this context, serve as a communication tool used in the instructional process to convey information from the teacher to students, to stimulate their engagement in learning activities (Bakhruddin et al., 2021). However, it is still commonly observed that students struggle to translate physics concepts into mathematical forms, which in turn can negatively affect their learning motivation.

A review of the literature shows that student worksheets based on Problem-Based Learning (PBL) should improve affective dimensions such as learning motivation, interest, or attitude toward the subject (Hanipah et al., 2018). However, most studies have focused on students' cognitive outcomes, such as their ability to solve problems or understand concepts (Astuti et al., 2023; Doyan et al., 2021). Therefore, there is a need for an effective learning tool for both teachers and students, such as a student worksheet based on the problem-based learning model. This tool is intended to help students not only understand physics concepts theoretically but also apply them in various relevant contexts. The student worksheet is designed to provide clear and structured guidance in accordance with the syntax of the problem-based learning model, enabling students to engage in exploration and reflection on the physics material being studied. An example of a problem that could trigger the PBL process is designing an outdoor concert in a densely populated area and near a hospital, as the team must provide the best sound quality to the audience without disturbing the surrounding residents. Sound wave principles must be used to determine the location of the speakers and sound specifications to achieve this balance. Through the use of student worksheets grounded in the problem-based learning approach, it is expected that students will improve their mathematical representation skills while also fostering their learning motivation.

▪ METHOD

Participant

The research was conducted at SMA Negeri 1 Godean, Yogyakarta, with a sample consisting of 33 eleventh-grade students. The sample was drawn from a regular class, selected using a random sampling technique. The class represents a typical instructional setting with a mix of academic abilities, making it suitable for evaluating the general effectiveness of the intervention. The type of research used in this study is quantitative research with a pre-experimental design approach. Quantitative research was chosen because it aims to examine the effect of a specific treatment under relatively controlled conditions (Sugiyono, 2016).

Research Design and Procedures

This study was conducted over a period of two weeks, from April 28 to May 9, 2025. The design employed is the one-group pretest-posttest design, which involves a single group of subjects that receives a treatment, with measurements taken before (pretest) and after the treatment (posttest). The purpose of this study is to determine the effect of using a problem-based learning (PBL) student worksheet on improving students' mathematical representation skills and learning motivation in the topic of sound waves. This study consisted of several stages. First, students were given a pre-test to measure their mathematical representation skills and learning motivation before the learning began. Next, they studied the material "Sound Waves" in three meetings. After completing the material, students were given a post-test to evaluate the development of their mathematical representation skills and learning motivation. The results of the pre-test and post-test were compared to assess the effectiveness of the problem-based learning model in improving students' mathematical representation and learning motivation on the sound wave material.

Instrument

The treatment given to the sample involved learning activities using the Problem-Based Learning model along with student worksheet learning media, aimed at improving students' mathematical representation skills and learning motivation. The student worksheet used in this study was previously validated by both expert validators (in content and pedagogy) and practitioner validators (school physics teachers). The worksheet consisted of five main sections, each aligned with the syntax of the PBL model as proposed by (Tan et al., 2009), namely: (1) Problem Orientation, (2) Organizing Students to Learn, (3) Guiding Individual and Group Investigation, (4) Developing and Presenting Work, and (5) Analyzing and Evaluating Problem-Solving Process. Each section of the worksheet contained activities that encouraged exploration and reasoning. For instance, in the Problem Orientation section, students were presented with a contextual problem related to everyday life, such as: "Why does the pitch of an ambulance siren seem to change as it moves past us?" This real-life question served to stimulate curiosity and relate the concept of sound waves to the Doppler Effect. Students were then guided to analyze graphical representations of waveforms, calculate frequency and wavelength, and derive relevant formulas based on experimental data. To stimulate mathematical representation skills, the worksheet included dedicated spaces for students to: (a) draw wave graphs, (b) construct concept maps, (c) derive equations, and (d) solve computational problems using appropriate symbols and units. This design ensured that students actively engaged with various forms of mathematical representation, including visual, symbolic, and numerical.

In parallel, the pretest-posttest instruments for mathematical representation and the learning motivation questionnaire were also validated prior to use. The motivation questionnaire was developed based on the Self-Determination Theory (SDT) by Deci & Ryan, as adapted in educational settings. The instrument measured four key dimensions of student motivation: intrinsic motivation, extrinsic motivation, perceived competence, and autonomy. The development of the instrument referred to recent studies such as (Howard et al., 2017), which emphasized the multidimensional structure of motivation in classroom settings.

Data Analysis

The quantitative data analysis techniques employed in this study included both descriptive and inferential statistical analyses. Descriptive statistical analysis was used to calculate the increase in variables before and after the learning intervention. The descriptive analysis utilized the normalized gain (n-gain) score. Inferential statistical analysis was carried out using a paired sample t-test. This test is used to determine whether there is a statistically significant difference in the sample before and after the treatment. A paired sample t-test can be applied when the data are normally distributed. To test for normality, the Kolmogorov-Smirnov and Shapiro-Wilk tests were used, as the sample size was fewer than 50. In addition, Cohen's d was used as an inferential statistical measure to determine the effect size, which indicates the magnitude of the influence of using the Problem-Based Learning-based student worksheets.

▪ RESULT AND DISSCUSSION

The research data were obtained from students' pre-test and post-test scores, as well as questionnaires administered before and after the learning intervention. The data were first analyzed using the Kolmogorov-Smirnov and Shapiro-Wilk normality tests to determine whether the data were normally distributed and met the assumptions required for parametric testing. The results of the normality test for the mathematical representation variable are presented in the following table.

Table 1. Normality test results using SPSS software

Tests of Normality										
		Kolmogorov-Smirnov[a]			Shapiro-Wilk					
		Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**	**Mean**	**Std. Error**
Mathematical Representation	Pretest	0.111	33	.200*	0.974	33	0.584	50.93	1.87
	Posttest	0.084	33	.200*	0.982	33	0.850	94.12	1.51
Learning Motivation	Pretest	0.115	33	.200*	0.955	33	0.190	48.51	0.65
	Posttest	0.109	33	.200*	0.970	33	0.473	50.51	0.56

As shown in Table 1, the Sig. values from both the Kolmogorov-Smirnov and Shapiro-Wilk normality tests are greater than 0.05. This indicates that the pre-test and post-test data for students' mathematical representation ability and learning motivation are normally distributed.. The overall analysis results of the N-Gain of students' mathematical representation ability and learning motivation in each indicator are presented in Figures 1 and 2.

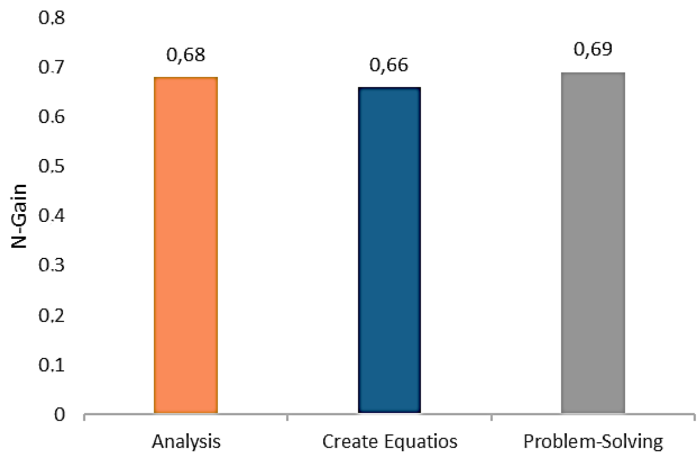

Figure 1. Graph of mathematical representation

Figures 1 and 2 show the N-Gain scores for each indicator of students' mathematical representation ability and learning motivation. Figure 1 clearly shows the problem meme indicator with the highest N-Gain score, at 0.69. This is followed by the analysis indicator with an N-Gain score of 0.68, and the equation creation indicator with an N-Gain score

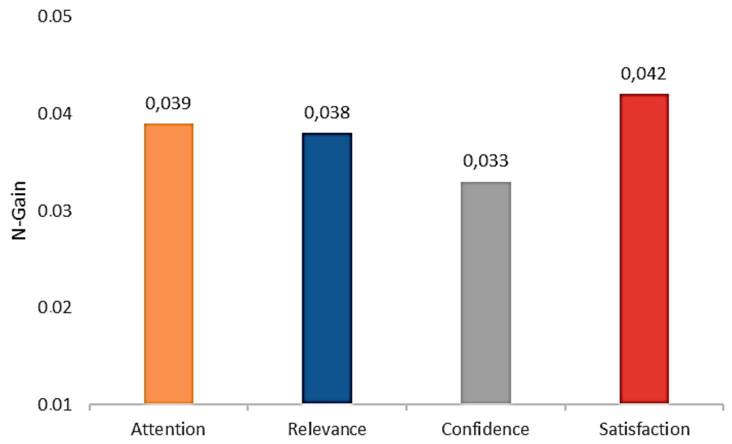

Figure 2. Learning motivation

of 0.66. All mathematical representation indicators, based on these results, are in the moderate category, with an average N-Gain score of 0.67. These results are also supported by a paired-samples t-test, which shows a Sig. (2-tailed) value of 0.000 < 0.05 indicates a significant difference in students' mathematical representation ability due to the treatment. In Problem-Based Learning, students are guided to develop alternative solutions to everyday problems. These problems are then analyzed, and students find solutions. This activity enables better analysis and problem-solving indicators compared to conventional learning. Furthermore, students' activities in analyzing equations to solve problems improve their skills in constructing mathematical equations from other representations.

This indicates that Problem-Based Learning has quite a positive effect on the development of students' mathematical representation abilities in the aspects of analysis, creating equations, and solving problems. Problem-Based Learning has the potential to significantly improve students' mathematical representation abilities compared to conventional learning. This increase is due to the fact that student worksheets with the Problem-Based model on the topic of Sound Waves can train students' mathematical representation abilities.

In contrast, Figure 2 shows that all indicators of learning motivation are in the low category. The N-Gain score for the satisfaction indicator is 0.042, followed by the attention and relevance indicators with scores of 0.039 and 0.038, and the self-confidence indicator with 0.033. The overall average N-Gain score for the learning motivation indicators is 0.038. The paired-sample t-test also yielded a Sig. (2-tailed) value of 0.055 > 0.05, indicating that the difference in motivation scores is not statistically significant at the 0.05 level. Therefore, it can be concluded that although there is a slight difference in scores for each indicator after the treatment, it is not statistically significant. This minimal increase suggests that the intervention, in its current form, has little or no practical impact on students' learning motivation. Several factors may explain these results, such as the design of the worksheets, which, although effective in improving mathematical representation, may not sufficiently address the essential psychological needs for motivation, namely autonomy, competence, and relatedness, as emphasized in Self-Determination Theory (Ryan & Deci, 2000). Without addressing these needs, instructional materials may fail to produce meaningful changes in students' intrinsic motivation.

The low improvement in students' learning motivation also indicates that instructional design alone is not sufficient to significantly boost affective aspects of learning. While Problem-Based Learning (PBL) provides a cognitive challenge through problem-solving and representation tasks, it may not automatically engage students emotionally or psychologically unless these tasks are connected to students' real-life experiences or interests. Research shows that relevance and personal connection are key drivers of motivation (Keller, 2008) . In this study, even though the learning material was structured with real-world problems, it is possible that the context did not resonate enough with students' personal lives to stimulate strong engagement or internal drive.

Although not statistically significant, there is an indication of improved student learning outcomes following the treatment, as reflected in the difference in mean scores. This suggests that the application of the problem-based learning model holds potential in enhancing student understanding, particularly in the topic of sound waves, which is abstract and conceptually challenging. The problem-based learning model is designed to engage students actively in the learning process through real-world problem solving, which aligns with previous findings that problem-based learning can develop higher-order thinking skills and mathematical representation abilities (Ayuni et al., 2020; Radiansyah et al., 2023).

The non-significant results may be attributed to several factors. One key factor is the relatively short duration of the implementation, which may not have been sufficient to yield a statistically significant impact on student achievement. This aligns with previous studies that emphasize how problem-based learning requires time and adaptation, as students need to get accustomed to a learning model that demands independence and collaboration (Sianturi et al., 2020). In addition, the cognitive demands of problem-based learning might have inadvertently drawn students' focus away from affective engagement. As students grappled with challenging tasks involving mathematical representation such as deriving formulas, interpreting graphs, and solving complex problems their cognitive load may have increased significantly. According to Cognitive Load Theory, when learners allocate most of their mental resources to process new and challenging content, affective engagement, such as motivation, can be deprioritized (Sweller et al., 2019) .

Another factor is the limited sample size of 33 students, which could affect the statistical analysis, especially when the observed differences in scores are small. In experimental research, a small sample size may result in an underpowered study, meaning it lacks the statistical power to detect actual differences (Santoso, 2020). Statistical power refers to the ability of a test to find a significant effect when there is one. With fewer participants, the results become more sensitive to random variations, and the standard error increases, making it harder to detect the differences between pretest and posttest scores. This can lead to a situation where the study concludes that there is no effect, even though one exists.

In this study, it is possible that the increase in students' motivation, although small, was real, but the small sample size prevented it from reaching statistical significance. Therefore, future research should consider using a larger sample size to increase the accuracy and reliability of the results, especially when measuring psychological variables like motivation that often show small or gradual changes. The results of the paired sample t-test for mathematical representation ability and learning motivation are shown in Table 2.

Table 2. Paired sample T-Test for mathematical representation and learning motivation

Variable	Mean	Std. Deviation	Std. Error Mean	Sig. (2-tailed)
Pretest – Posttest Mathematical Representation	-33.18182	14.11439	2.45700	0.000
Pretest – Posttest Learning Motivation	-2.00000	5.76628	1.00378	0.055

The paired sample t-test conducted previously does not provide information on the magnitude of the effect resulting from the treatment. To determine the effect size or the extent of improvement gained, Cohen's d test was performed. The following presents the results of the Cohen's d calculation.

Table 3. Results of cohen's d calculation

Variable	$\underline{D}$	S_D	d
Mathematical Representation	33.1818182	14.11439	2.35092116
Learning Motivation	1.8488	5.76628	0.32061952

Based on the calculation results, the Cohen's d value for mathematical representation ability is 2.35. According to Cohen's (1988) criteria, Click or tap here to enter text.this value falls into the very large effect size category. This result indicates that the use of student worksheets based on the problem-based learning model has a significant impact on improving students' mathematical representation abilities. With worksheets, students are encouraged to master concepts with a good understanding, and they are trained to solve problems independently, making it more effective for improving knowledge. This substantial effect is likely due to the characteristics of problem-based learning, which emphasize critical thinking, analytical reasoning, and collaborative problem-solving processes skills that are highly relevant for developing conceptual and mathematical representations in physics learning (Hake, 1998; Kurniawan et al., 2025).

Furthermore, the student worksheets were designed in a contextual and interactive manner, enabling students to build a deeper understanding of sound wave concepts through graphical, verbal, symbolic, and mathematical representations. This improvement is consistent with previous research findings, which state that problem-based learning strategies can enhance students' conceptual representations in science and mathematics subjects (Sari et al., 2023; Syawaly & Hayun, 2020).

Meanwhile, the Cohen's d value for students' learning motivation is 0.32, which is categorized as a small effect size. This means that although there was an increase in the average score of learning motivation from the pre-test to the post-test, the improvement was not practically substantial. Several factors may have contributed to this outcome, including the short duration of implementation, students' readiness to adopt a new learning approach, as well as external factors such as the learning environment and time constraints. Nevertheless, this small effect still holds educational significance. According to (Marzano, 2017), even a minor improvement in learning motivation can have long-term impacts on student engagement and academic achievement. Therefore, these findings suggest that further development of problem-based learning media and strategies should be pursued in order to optimize the affective aspects of learning, particularly student motivation.

The positive impact on students' mathematical representation skills can be explained through Vygotsky's Social Constructivist Theory, which emphasizes the role of social interaction and scaffolding in the development of higher-order thinking skills (Vygotsky, 1979). The problem-based learning model, supported by structured student worksheets, provides opportunities for guided problem-solving, peer discussion, and teacher facilitation elements that help students progress through their Zone of Proximal Development (ZPD) and construct deeper mathematical understanding.

On the other hand, the minimal improvement in learning motivation may be better understood through the lens of the Expectancy-Value Theory of Motivation (Eccles & Wigfield, 2020). According to this theory, a student's motivation to engage in a task depends on two main factors: their expectation of success and the perceived value of the task. If students are unsure of their ability to succeed with a new and challenging learning model, such as problem-based learning, or if they do not perceive the tasks as meaningful or personally relevant, their motivation may remain low despite improvements in cognitive performance. This suggests that future interventions should not only support cognitive development but also intentionally foster students' beliefs in their own competence and the value of the learning experience, especially in affective domains such as motivation.

To enhance both mathematical representation and motivation simultaneously, future learning tools or interventions could integrate features that more directly support autonomy, competence, and relatedness. For example, allowing students to select problem contexts, collaborate in small groups, and reflect on their learning process may create a more motivating environment. Combining PBL with motivational scaffolding techniques such as goal setting, feedback, and student choice could optimize the effectiveness of the instructional design. Therefore, while PBL has shown strong potential in fostering cognitive outcomes, additional support structures are needed to address students' motivational needs comprehensively.

▪ CONCLUSION

Based on the research results, the implementation of student worksheets based on the problem-based learning model on the topic of sound waves in Grade XI at SMA Negeri 1 Godean showed an increase in the average post-test scores compared to pre-test scores in terms of mathematical representation skills and learning motivation. The effectiveness test, using Cohen's d, revealed an effect size of 2.35 on mathematical representation ability, which falls into the very large category. This indicates that the problem-based learning model is highly effective in improving students' cognitive aspects, particularly in developing conceptual and mathematical representations in physics learning. Meanwhile, the effect size on learning motivation was 0.32, categorized as a small effect, indicating that while the model had a positive impact on motivation, the influence was not yet optimal.

Overall, student worksheets based on problem-based learning have been proven to provide a practical, positive impact on learning, especially in the aspect of mathematical representation. Although the effect on motivation was not statistically significant and still relatively small, the findings highlight the potential of further developing the problem-based learning model as a more meaningful and contextual alternative in physics education. Further studies are needed with more extended implementation periods, larger sample sizes, and improved motivation instruments to yield stronger and more comprehensive results, particularly in understanding the interrelation between cognitive and affective aspects in science learning.

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