Jurnal Riset dan Kajian Pendidikan Fisika
Vol. 13, No. 1 [April 2026], pp. 13-22

e-ISSN: 2355-620X
DOI: 10.12928/jrkpf.v13i1.1532

Development of a student worksheet on the problem-based learning model to improve mathematical representation ability and learning interest

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Abstract
This study addresses the low level of students' mathematical representation ability and learning interest in wave topics, highlighting the need for more effective instructional approaches. The study aims to develop and implement a student worksheet based on the Problem-Based Learning (PBL) model to improve these two aspects. A pre-experimental design with a one-group pretest–posttest format was employed, involving 34 students as research participants. Data were collected using pretest and posttest instruments to measure mathematical representation ability, along with a learning interest questionnaire. The data were analyzed using a paired-sample t-test to examine differences before and after the intervention, and the effect size was calculated to determine the magnitude of the impact. The results indicate that the PBL-based worksheet has a positive and significant effect on students' mathematical representation ability ($p < 0.001$) with a large effect size ($d = 2.1$). However, its effect on learning interest is not statistically significant ($p = 0.318$) with a small effect size ($d = 0.18$). In conclusion, the PBL approach is effective in enhancing students' mathematical representation ability, but less effective in fostering learning interest. These findings imply that integrating additional or complementary instructional strategies is necessary to improve students' interest in physics more effectively.

Keywords: Learning interest, Mathematical representation, Problem-based learning

Article submitted 2025-06-13. Revision uploaded 2026-03-04.
Accepted for publication 2025-04-06.
Available online on 2026-04-30.
https://doi.org/10.12928/jrkpf.v13i1.1532

I. Introduction

Humans possess an inherent drive to grow and learn as part of the ongoing advancement of civilization. In this regard, education plays a vital role in equipping students to contribute meaningfully to their surroundings. Through education, individuals can enhance their quality of life by developing knowledge, skills, and experience [1]. As the demands of the industrial and technological era continue to evolve, education must also adapt to prepare a generation of proactive learners. Students are no longer positioned as passive recipients of information; instead, they are expected to process, critique, reinterpret, and actively engage in scientific dialogue [2]. In line with this expectation, STEM-based learning tools have been shown to significantly improve students’ literacy and academic performance at the senior high school level [3]. Consequently, education plays an indispensable role in the natural sciences, particularly physics, which serves as a fundamental component in shaping students’ scientific understanding.

Mathematical representation ability plays a crucial role in supporting students' understanding during the learning process. This ability can be defined as a cognitive process through which students translate and conceptualize mathematical ideas into various forms, such as symbols, graphs, diagrams, or other mathematical models [4]. It refers to students' capacity to communicate ideas or solutions using the language of mathematics [5]. Moreover, the mathematical representation reflects the extent to which students can connect mathematical concepts to real-world problems and contexts. This competence not only indicates conceptual understanding but also demonstrates logical and abstract thinking skills that are essential for solving problems in a structured manner. However, empirical evidence shows that many students still struggle to apply conceptual and mathematical reasoning when solving physics problems, particularly in fluid topics, underscoring the need for instructional approaches that strengthen both conceptual understanding and problem-solving skills [6]. Previous studies further report that students often struggle to represent mathematical ideas clearly while working through physics tasks, highlighting the importance of learning approaches that actively facilitate connections among diagrams, equations, and verbal reasoning [7], [8]. This condition indicates that improving students' mathematical representation ability is a pedagogical necessity in physics education, particularly in topics such as waves that require the integration of graphical, symbolic, and quantitative reasoning. Therefore, instructional models that systematically train students to connect multiple forms of representation are needed to minimize the gap between conceptual understanding and mathematical application.

Learning interest is one of the primary internal factors that influences how students engage in the learning process and what they ultimately achieve, particularly in physics. Students' attitudes toward learning largely determine whether the experience is perceived positively or negatively. These attitudes can be reflected in expressions of satisfaction, enthusiasm, and excitement, or conversely, in feelings of anxiety and disinterest [1]. High levels of learning interest encourage students to be more diligent, persistent, and enthusiastic, which in turn positively affects their academic performance. In contrast, low interest often leads to reduced focus, motivation, and engagement in exploring physics concepts in greater depth. Students' negative perceptions of physics, especially regarding its difficulty and limited relevance to everyday life, further emphasize the need for more contextual and motivating instructional approaches, such as Problem-Based Learning (PBL) [9]. Consistent with this view, low interest in physics remains one of the major factors contributing to limited learning achievement in the subject [10]. This condition indicates that enhancing learning interest is not merely a complementary aspect but a key element in fostering effective and meaningful physics learning. In this regard, instructional approaches that provide contextual and relevant learning experiences are essential for promoting students' active engagement and sustained effort in understanding physics concepts more deeply.

The Problem-Based Learning (PBL) model is an effective instructional approach for fostering meaningful, context-based learning in physics. Compared to conventional teaching methods, PBL provides students with more meaningful opportunities to develop critical thinking, collaboration, and communication skills in physics classrooms [11]. Students' limited conceptual understanding when exposed to a single form of representation highlights the need to design PBL materials that integrate multiple mathematical representations to promote more coherent and applicable understanding [12]. By positioning students at the center of the learning process, PBL transforms them from passive recipients into active constructors of knowledge through structured problem-solving activities [13]. This approach enhances student engagement while fostering higher-order thinking skills and independence in learning. The problem-solving processes embedded in PBL also encourage continuous practice of mathematical abilities [14], which aligns with the importance of strengthening mathematical representation skills in physics, a discipline that is inherently quantitative and symbolic. As part of active STEM-oriented instructional strategies, PBL supports students in addressing real-world challenges by promoting critical thinking, collaboration, and meaningful use of digital tools [15]. Furthermore, PBL requires active participation throughout the learning process, resulting in richer and more meaningful learning experiences [16]. Consequently, implementing PBL is highly relevant for improving the quality of physics instruction, particularly in abstract topics such as vibrations and waves, which often require active engagement to be fully understood.

The Problem-Based Learning (PBL) model has demonstrated positive impacts on learning physics concepts, particularly in complex and abstract topics such as wave phenomena. A study conducted by Hermanto [17] reported that the GC-PBL (Guided Context-and Problem-Based Learning) approach significantly improved students' conceptual understanding of sound waves, with students showing substantially greater gains compared to those taught through traditional methods. Similar findings were reported by Yusuf [18], who integrated PBL with Google Classroom and observed significant improvements in both learning activity and achievement in understanding sound waves. However, most previous studies have primarily emphasized conceptual understanding or general learning outcomes. Limited research has specifically examined how PBL contributes to the development of students’ mathematical representation skills and learning interest in wave-related topics. These two aspects are crucial for achieving a comprehensive understanding, as mastering wave concepts requires more than memorization; it involves connecting physical phenomena with graphs, equations, and mathematical visualizations. Incorporating real-world contexts into physics instruction has also been shown to enhance students' critical thinking and problem-solving abilities by making abstract concepts more concrete and meaningful [19]. While previous studies have predominantly examined the impact of PBL on conceptual understanding, limited research has simultaneously investigated its effect on students’ mathematical representation skills and learning interest within wave topics. This study addresses this gap by integrating cognitive and affective dimensions into the evaluation of PBL implementation.

In contemporary physics classrooms, students are expected to do more than merely understand scientific concepts; they are also encouraged to articulate their ideas and reasoning clearly. This shift highlights the importance of positioning scientific communication as a central objective of learning. PBL aligns closely with this goal, as it engages students in meaningful activities such as identifying problems, discussing ideas collaboratively, and presenting evidence-based solutions [20]. Research indicates that learning environments structured around investigation, collaboration, and problem-solving, core characteristics of PBL, can significantly enhance students' scientific communication skills [21], [22]. However, several studies report that students' scientific literacy in physics remains relatively low. Many students experience difficulties interpreting data, drawing evidence-based conclusions, and explaining scientific phenomena coherently and logically [23], [24]. This condition underscores that although PBL theoretically holds strong potential to foster scientific communication through discussion and evidence-based argumentation, empirical investigations specifically examining its contribution to students’ scientific communication skills in physics learning contexts remain limited and require further exploration.

This study aims to examine the effect of PBL implementation on improving students' mathematical representation skills and learning interest in physics, particularly in the context of wave topics. These two variables were selected for their strategic roles in fostering conceptual understanding and promoting active engagement throughout the learning process. In addition, scientific communication skills are examined descriptively as a supplementary outcome of PBL implementation, given their importance for articulating ideas, explaining concepts, and participating in scientific discourse in physics classrooms. Beyond cognitive and affective outcomes, contemporary physics learning also emphasizes students' ability to articulate reasoning and communicate scientific ideas coherently. Since PBL inherently involves discussion, argumentation, and the presentation of solutions, examining students' scientific communication skills provides complementary insight into how they express and justify their understanding after the intervention. Through this investigation, the study contributes to the development of instructional strategies that not only strengthen cognitive and affective dimensions of learning but also support the advancement of broader scientific competencies. The following three research questions guide this study:

1. Does the implementation of the Problem-Based Learning (PBL) model significantly improve students’ mathematical representation ability in wave topics?
2. Does the implementation of the Problem-Based Learning (PBL) model significantly improve students’ learning interest?
3. How are students’ scientific communication skills characterized following the implementation of the PBL model?

II. Methods

This study employed a quantitative approach using a pre-experimental design, specifically a one-group pretest-posttest design. This design was selected to examine changes in the variables under investigation following the implementation of the instructional model, without involving a comparison group. In this design, a single group of participants was administered a pretest, followed by the instructional intervention, and subsequently a posttest [25]. The difference between pretest and posttest scores was analyzed to measure improvements after the intervention [26], [27]. Although this design has limitations in controlling external variables and does not fully establish causal relationships, it is considered appropriate for investigating the preliminary effectiveness of an instructional model in a classroom setting.

The participants of this study were 33 eleventh-grade students from a public senior high school in Sleman. The research subjects were selected through purposive sampling, as the selected class was studying wave phenomena at the time of data collection. The selection was based on curriculum alignment and the feasibility of implementing the intervention within the available instructional schedule. Given the pre-experimental nature of the study, only one intact class was involved to preserve the natural learning context. Although purposive sampling may introduce selection bias, a pretest was administered to establish baseline performance before the intervention. This study examined one independent variable and two dependent variables. The independent variable was the implementation of the Problem-Based Learning (PBL) model, while the dependent variables were students' mathematical representation ability and learning interest.

The research was conducted in three major phases: preparation, implementation, and data analysis. During the preparation phase, the researcher conducted an initial survey and obtained formal permission from the school, developed instructional materials in the form of a student worksheet integrating the Problem-Based Learning (PBL) model for the wave topic, and prepared the research instruments. The instruments consisted of a mathematical representation test administered as a pretest and posttest, and a learning interest questionnaire. Before implementation, the instruments were validated to ensure validity and reliability [28]. Content validity was assessed through expert judgment, and reliability was assessed using internal consistency analyses. Content validity was assessed by five experts using Aiken's V, yielding values ranging from 0,93 for mathematical representation to 0.97 for learning interest, indicating high content validity. The reliability analysis showed Cronbach's alpha coefficients of 0.88 and 0.71, indicating high internal consistency.

Mathematical representation ability was measured using an essay-based test that assessed students' ability to express physics concepts through mathematical equations, graphs, and symbolic representations. Meanwhile, students' learning interest was measured using a Likert-scale questionnaire reflecting attention, engagement, and enthusiasm toward physics learning. Both instruments underwent content validation through expert judgment involving two physics education experts who evaluated item relevance, clarity, and alignment with learning objectives. Revisions were made based on their feedback before implementation. Content validation through expert evaluation is essential to ensure that the instrument adequately represents the intended construct [29].

The implementation phase began with a pretest to assess students' initial abilities in mathematical representation. The instructional intervention was conducted over several class meetings using the Problem-Based Learning (PBL) model. The learning activities followed the main stages of PBL, including problem orientation, group investigation, solution development, and presentation of findings. Throughout the sessions, students engaged in problem-solving tasks designed to promote active participation, collaboration, and critical thinking. After the intervention, a posttest was administered to assess changes in students' mathematical representation abilities. In addition, students completed a learning interest questionnaire to examine their responses and engagement toward the PBL-based instruction. To ensure fairness, the same teacher, instructional duration, learning materials, and assessment procedures were maintained consistently throughout the intervention.

The final phase involved data analysis. Data were collected from the pretest, posttest, and learning interest questionnaire, and analyzed using both descriptive and inferential statistics. Descriptive analysis included calculating the mean and standard deviation to summarize students’ performance and responses. Frequency distributions were also generated to provide an overview of student response patterns [30]. Before data collection, formal permission was obtained from the school administration to conduct the study. The research was implemented as part of regular classroom instruction and did not interfere with students' academic activities. Students were informed of the study's purpose, and their participation was voluntary. All collected data were kept confidential and anonymized to ensure participants' privacy.

Inferential analysis was conducted using a paired-samples t-test to determine whether there was a statistically significant difference between pretest and posttest scores in students' mathematical representation ability at the 0.05 significance level. Before conducting the t-test, a normality test was performed to ensure the data met the assumptions of parametric analysis. Descriptive analysis of the learning interest data involved calculating the percentage of students classified into high, medium, and low interest categories based on predetermined scoring criteria. Additionally, the practical effectiveness of the PBL model was examined by calculating Cohen's d effect size to determine the magnitude of the observed improvement [31].

$$d = \frac{\bar{X}_{\text{post}} - \bar{X}_{\text{pre}}}{SD_{\text{pooled}}} \tag{1}$$

The scientific communication skills questionnaire consisted of 24 statements, each measured on a 4-point Likert scale from 1 (strongly disagree) to 4 (strongly agree). The items were designed to assess several indicators of scientific communication, including the ability to express ideas clearly, construct evidence-based arguments, respond to others' opinions, and present discussion results systematically. The data were analyzed descriptively using percentages to describe students' scientific communication skills across each indicator.

III. Results and discussion

Research results showed that the data were normally distributed ($p > 0.05$); therefore, parametric analysis was considered appropriate. The results of the paired-samples t-test show a p-value of < 0.001, indicating a statistically significant difference between students' pretest and posttest scores in mathematical representation ability following the implementation of the PBL model. This finding indicates that students demonstrated measurable improvement after participating in the PBL-based instruction.

Furthermore, the calculated effect size is 2.1. Based on Cohen's criteria ($d \geq 0.8$), this effect size is categorized as very large [32]. This result suggests that the improvement observed is not only statistically significant but also practically meaningful. The substantial effect size indicates that the PBL approach is strongly associated with enhanced mathematical representation skills in this study [33].

These findings are consistent with previous studies that have reported that PBL supports the development of higher-order thinking and representational competencies. The observed improvement may be related to the characteristics of PBL, which actively involve students in exploring, modeling, and interpreting problems in various mathematical forms and processes that are central to the development of mathematical representation ability.

Table 1. Average mathematical representation score

Test	Average
Pretest	18.79
Posttest	64.85

Table 2. Mathematical representation of t-test results

Standard Deviation	Sig. (2-Tailed)
21.204	0.00

This study's findings are consistent with Carli [34], who reported that when students are guided to develop a deeper conceptual understanding in physics, they tend to demonstrate higher engagement and improved performance in solving quantitative problems. These findings also align with the characteristics of Problem-Based Learning, which emphasize contextual problem-solving and the use of multiple representations. Such instructional approaches encourage students to construct knowledge through symbolic, graphical, and verbal forms of processes that are fundamental to the development of mathematical representation ability. Furthermore, learning tools designed to promote higher-order thinking skills (HOTS) have been shown to enhance critical thinking, which plays a crucial role in strengthening students' representational competence [35]. The improvement in mathematical representation ability was observed across three key dimensions: conversion between representations, mathematical problem-solving, and communication using mathematical representations. In particular, PBL strengthened students' ability to translate information across different representational forms and to apply and communicate mathematical representations more systematically in problem-solving contexts.

Regarding learning interest, the paired-samples t-test results show a p-value of 0.318 ($p > 0.05$), indicating no statistically significant difference between pretest and posttest scores. Although the effect size ($d = 0.18$) falls within the small category according to Cohen's criteria, this suggests only a limited practical impact of the PBL model on students' learning interest.

This modest effect may be attributed to several factors. Learning interest is closely associated with affective and personal dimensions that typically develop over sustained instructional experiences. The relatively short duration of the intervention may not have been sufficient to generate substantial changes in students' intrinsic motivation or emotional engagement. In addition, while PBL encourages autonomy and collaboration, students accustomed to teacher-centered instruction may need an adjustment period before fully benefiting from this approach. Nevertheless, the slight increase in posttest scores indicates that PBL may have the potential to enhance learning interest, particularly when implemented over a longer period or supported by complementary affective-oriented strategies.

Table 3. Average mathematical representation score

Test	Average
Pretest	30.23
Posttest	31.31

Table 4. Mathematical representation of t-test results

Standard Deviation	Sig. (2-Tailed)
5.39	0.32

The non-significant increase in learning interest may be attributed to the relatively short duration of the intervention, as affective constructs typically require sustained exposure to instructional innovation. Interest development is often gradual and influenced by prior dispositions, suggesting that short-term implementation of PBL may not be sufficient to produce measurable affective change. Although the increase in learning interest is not statistically significant, a slight upward trend is observed, suggesting that PBL may help foster students' situational interest within limited instructional time. Previous studies have shown that short-term, context-based interventions can initiate improvements in student engagement [36]. In this study, PBL activities grounded in real-world problems and active participation may have stimulated students' interest to some extent; however, enhancing learning interest generally requires sustained and consistent implementation. Therefore, future instructional practices may need to integrate complementary affective strategies, such as constructive feedback, emotional engagement, and interactive learning media, to support the long-term development of students' intrinsic motivation [37].

In addition to the cognitive and affective variables, this study also examined students' scientific communication skills as a descriptive component. Each student's responses were totaled, resulting in individual overall scores. These total scores were then categorized into five levels to represent the degree of scientific communication ability. The categorization was conducted by evenly dividing the possible score range (24-96) into five intervals, thus allowing for classification into very low, low, moderate, high, and very high levels. This finding indicates that students generally demonstrated adequate ability to express scientific ideas, construct arguments, and engage in academic discussion during the learning process.

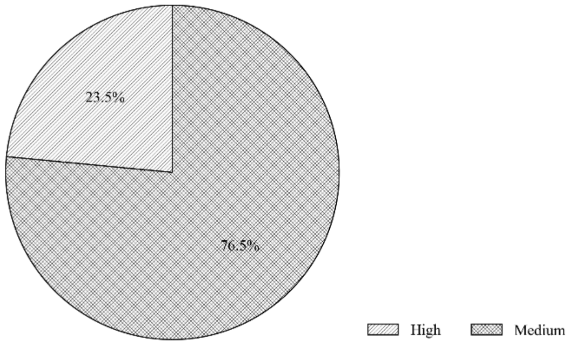

Figure 1. Percentage of scientific communication

The analysis revealed that 8 of 34 students (23.5%) were classified in the high category, while 26 (76.5%) were in the moderate category. No students were found in the very low, low, or very high categories. These findings indicate that the majority of students' scientific communication skills were at a moderate level, with a smaller portion already demonstrating a higher level of competence. While no inferential analysis was conducted, the descriptive trends suggest a potential positive influence of PBL on students' scientific communication skills.

This result indicates that the implementation of PBL was associated with a generally positive level of students' scientific communication skills. Previous studies have reported that the integration of interactive multimedia and problem-based learning in physics can enhance student engagement, facilitate conceptual understanding, and promote scientific communication through collaborative activities such as group discussions and poster presentations [38], [39]. The PBL structure, which emphasizes collaborative problem-solving and student-centered learning, provides opportunities for students to articulate ideas, explain their reasoning, and engage in peer interaction. In this context, scientific communication extends beyond conveying ideas to fostering habits of openness and cooperation within academic discourse [40]. Nevertheless, the absence of students in the very high category suggests that further instructional refinement is needed to optimize students' proficiency in scientific communication.

This finding suggests that although PBL may provide a conducive environment for the development of students' scientific communication, further instructional refinement is needed to strengthen this competency. Future instructional practices could place greater emphasis on structured scientific discussions, data-driven presentations, and the development of coherent and logically organized arguments. In addition, future studies may explore how multidisciplinary learning environments, such as those implemented in challenge-based learning, can support students in integrating knowledge across domains while enhancing collaboration and communication skills [41]. Strengthening these components is essential not only for achievement in physics but also for promoting broader scientific literacy and fostering students' academic confidence.

The improvement in students' mathematical representation ability observed in this study was accompanied by an increase in learning interest, indicating an interconnected relationship between cognitive and affective dimensions of learning. The relationship between interest and academic performance has been reported to remain consistent across different types of problems, including intramathematical, word, and modeling problems, all of which inherently require translation and mathematical representation across varied contexts [42]. This evidence suggests that interest functions not merely as an emotional response to instruction but as a factor closely linked to students' cognitive achievement. Furthermore, motivation and self-concept have been identified as significant predictors of mathematics performance, reinforcing the idea that academic outcomes are inseparable from students' internal dispositions [43]. Within problem-based instructional settings, increased situational engagement has been observed when students participate in contextual and challenging problem-solving activities [44]. Taken together, these findings support the interpretation that the enhancement of mathematical representation ability in this study resulted from the interaction between the PBL design and strengthened learning interest, which promoted deeper cognitive engagement.

Overall, the findings demonstrate that implementing the Problem-Based Learning (PBL) model significantly improved students' mathematical representation ability and interest in wave topics, as indicated by the statistical analysis. In addition, students' scientific communication skills were predominantly categorized at a good level based on descriptive percentage analysis. These results collectively confirm that all three research questions have been addressed, showing that PBL not only strengthens cognitive and affective dimensions of learning but also supports the development of students' scientific communication skills in physics classrooms.

Future research may also investigate how carefully designed digital media can enhance the effectiveness of problem-based learning in physics. The integration of simulations, instructional videos, and interactive tools may increase student engagement and facilitate conceptual understanding. Emerging technologies such as ChatGPT, PhET simulations, and educational YouTube content have demonstrated potential in supporting learning processes and therefore warrant further examination in physics classrooms [45]–[47]. In addition, physics learning supported by serious games has been reported to improve cognitive outcomes, learning interest, and problem-solving skills [48]. The incorporation of the 5E learning cycle model, which promotes inquiry-based and collaborative experiences, may further strengthen student engagement and conceptual understanding [49]. Finally, future studies may examine the integration of Problem-Based Learning with digital learning media, such as interactive e-books and online platforms, to optimize instructional effectiveness [50], [51]. Collectively, these directions highlight the importance of continuously innovating instructional design to foster students' cognitive development, communication skills, and overall scientific competence.

IV. Conclusions

The findings of this study demonstrate that implementing the Problem-Based Learning (PBL) model significantly improves students' mathematical representation skills in learning wave concepts. The statistical analysis revealed a significant difference between pretest and posttest scores, accompanied by a very large effect size, indicating a substantial impact of PBL on students’ ability to express and interpret mathematical representations. These results confirm that context-based and problem-oriented learning activities embedded in PBL effectively support the development of students’ representational competence in physics.

In contrast, the increase in students' learning interest following the implementation of PBL was not statistically significant, and the effect size was categorized as small. Although a positive trend was observed, the findings suggest that enhancing affective outcomes, such as learning interest, may require additional instructional strategies or a longer intervention duration. Therefore, while PBL proves highly effective in strengthening cognitive aspects related to mathematical representation, its influence on students' affective engagement appears more limited within the scope of this study.

Additionally, the descriptive analysis of students' scientific communication skills showed that most students were classified in the moderate to high categories. Although no inferential analysis was conducted for this variable, the findings indicate that PBL provides students with opportunities to engage in scientific discourse and articulate their reasoning. This suggests that PBL's contribution may extend beyond cognitive gains to support broader scientific competencies.

Despite these contributions, several limitations should be acknowledged. The study was conducted in a single class at a single school, which may limit the generalizability of the findings. The results should be interpreted as preliminary evidence within the studied context rather than as broadly generalizable conclusions. The relatively short duration of the intervention also restricts conclusions regarding the long-term effects of PBL, particularly on affective variables such as learning interest. Moreover, the reliance on self-report questionnaires and descriptive analysis may not fully capture the complexity of students' interests and communication skills.

Future research should involve more diverse samples across multiple schools and extend the duration of implementation to examine sustained instructional effects. Employing multiple data collection methods, such as classroom observations or interviews, would provide richer and more triangulated evidence. Further investigation into the impact of PBL on other essential 21st-century competencies, including critical thinking, collaboration, and scientific literacy, is also recommended to obtain a more comprehensive understanding of its educational potential.

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