

## IMPROVING CONCEPTUAL UNDERSTANDING OF TEMPERATURE AND PHASE CHANGE THROUGH PROBLEM-BASED LEARNING WITH MULTIREPRESENTATION MEDIA

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### Abstract :

This study aims to examine the effectiveness of Problem-Based Learning (PBL) supported by multirepresentation media in improving students' conceptual understanding of temperature and changes in the state of matter. A quantitative, quasi-experimental pretest–posttest design with non-equivalent control groups was used. The research participants consisted of two classes of 11th-grade science majors at SMA Negeri 1 Tumijajar, selected through cluster sampling. Data were collected through a test that measured seven indicators of conceptual understanding. The results showed a significant increase in conceptual understanding in both groups; however, the experimental group achieved much higher posttest scores and levels of improvement. The experimental group obtained an average N-gain of 0.68, while the control group achieved 0.49. Inferential analysis confirmed a significant difference in posttest scores between the groups, demonstrating the effectiveness of PBL supported by multirepresentational media in facilitating conceptual understanding. The improvement was particularly evident in higher-order indicators such as interpreting, comparing, explaining, and concluding. These findings suggest that integrating multi-representation media into PBL is highly effective as a cognitive scaffold to enhance students' ability to construct and translate abstract physics concepts, making learning more effective, meaningful, and cognitively structured.

**Keywords:** Conceptual Understanding, Problem-Based Learning, Multirepresentation

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## INTRODUCTION

In studying physics, students should understand concepts rather than just memorize physics formulas. Conceptual knowledge is knowledge in the form of understanding, definitions, characteristics, and components of an object. Many students face challenges in aligning their understanding with that of expert physicists, particularly in abstract topics (Isra & Mufit, 2023). The concepts of temperature and phase change are especially challenging because they involve processes that are not directly observable. Empirical studies indicate challenges in grasping concepts such as heat capacity, thermal equilibrium, and the relationship between temperature and heat transfer (Foroushani, 2019; Rodriguez et al., 2025; Trisnasari, 2024). Many students understand this material partially or procedurally and fail to connect the macroscopic, microscopic, and symbolic levels.

These difficulties not only reflect a lack of factual knowledge but also indicate challenges in constructing a coherent and meaningful conceptual framework. Such challenges can arise from students' initial understanding (preconceptions) and teaching approaches that emphasize procedural correctness rather than conceptual integration (Nurvermadi et al., 2025). If not addressed early on, these conceptual difficulties can continue into higher education and hinder the understanding of more complex concepts (Mufit et al., 2023). Difficulties in understanding the concept of heat are deep-rooted, structured, and difficult to overcome through traditional learning, emphasizing the importance of restructuring concepts through deliberately designed, student-centered learning strategies (Utama et al., 2025). The need for such conceptual restructuring can be addressed through problem-based learning (PBL), a student-centered form of learning that places students at the center of exploring problems, critically reflecting, and reconstructing their understanding of heat.

Many studies have examined the impact of PBL on physics learning, demonstrating its potential in strengthening conceptual understanding when designed as a process of knowledge reconstruction, rather than merely solving surface problems, thereby enhancing deeper understanding and better knowledge retention (Ali, 2019; Hafizah et al., 2024; Verawati et al., 2024). Findings from studies by Alfisyahrina et al. (2015) and Şenyiğit (2021) revealed that problem-based learning is more effective at improving conceptual understanding and overcoming misconceptions than lecture-based learning.

The constructivist problem-based learning model is appropriate for schools because it encourages students to actively construct knowledge, improve their ability to ask questions, foster positive and social attitudes, strengthen the connection between concepts and facts, and shift the role of students from passive to collaborative and participatory (Lubis et al., 2022). Although PBL provides a strong framework for encouraging exploration, reflection, and reconstruction of concepts, its effectiveness in strengthening conceptual understanding determined mainly by how those concepts are visualized and presented to students (Nicholus et al., 2024). PBL is generally effective, but it requires support from appropriate representations to develop students' conceptual understanding optimally.

Multiple representation is very suitable for teaching science that has abstract concepts. Learning science with multiple representations can provide a better conceptual understanding for the students (Simanjuntak et al., 2021). Multiple representations can be used in ways that adhere to common instructional design theories on the presentation side and simultaneously support deep-level understanding on the learners' side (Opfermann et al., 2017; Theasy et al., 2018). Students can build their knowledge through student-centered learning supported by the use of multi-representation teaching materials that train critical thinking skills, deep understanding, and independent learning (Jannah et al., 2022; Noeryana & Mubarok, 2022). The integration of multiple representations, including visual, graphic, mathematical, and verbal representations, can help students translate between representations and reconstruct coherent conceptual structures (Maries et al., 2017). Thus, the application of multiple representations in science learning not only facilitates a deeper understanding of abstract concepts but also strengthens students' ability to think critically, translate between representations, and independently build coherent conceptual structures through a student-centred approach.

The integration of problem-based learning with multirepresentation is positioned as a strategic approach to strengthening conceptual understanding in a more systematic and in-depth manner. The combination of PBL with multirepresentational media has been proven to improve mastery of fundamental concepts (Tiasutik et al., 2023), critical thinking skill (Mohamad et al., 2023), and learning outcome (Arifin et al., 2024). There are limited studies that specifically examine how PBL, assisted by multirepresentational media, strengthens indicators of conceptual understanding of abstract concepts such as temperature and changes in physical state.

Given the above challenges and the current state of education, there is a clear need to examine the synergy between innovative pedagogies, such as PBL, and the use of multirepresentational learning media. A comprehensive integration of these elements will not only optimize students' conceptual understanding but also reshape their concepts of physics to make them more accessible, relevant, and intellectually engaging (Putri et al., 2020). Therefore, this study offers novelty by empirically examining the effectiveness of integrating PBL and multirepresentational media on students' conceptual understanding, not only in general but also at the level of conceptual understanding indicators.

Based on this background, this study aims to examine the effectiveness of problem-based learning integrated with multirepresentational media in strengthening students' conceptual

understanding of temperature and phase change. This study is expected to contribute to the improvement of physics pedagogy by providing empirical evidence regarding learning approaches that systematically support conceptual reconstruction and build a more solid and coherent understanding of abstract physics phenomena.

## **RESEARCH METHOD**

### ***Research Design***

This study applied a quantitative approach, implementing a quasi-experimental design with a pretest-posttest nonequivalent control group (Cohen et al., 2007). The study examined the impact of the Problem-Based Learning (PBL) model, supported by multirepresentation-based media, on students' comprehension of temperature and phase-change concepts. This design included an experimental group that learned using the PBL model with multiple representations and a control group that learned using the traditional PBL model without any media support. Both groups took a pretest to assess their initial understanding of the concepts and a posttest to assess their improvement after the learning intervention. This design was selected because it facilitates a comparison of learning outcomes between groups that are not randomly assigned but are deemed equivalent.

### ***Research Target/Subject***

The subjects of this study were all eleventh-grade science students at SMA Negeri 1 Tumijajar enrolled in the course on temperature and phase change. The sampling method employed was cluster sampling, in which two intact classes were selected as the experimental and control groups. Class XI MIPA 1 was designated as the experimental group, whereas Class XI MIPA 2 functioned as the control group. Each class comprised thirty-two students. The experimental group received instruction through the Problem-Based Learning (PBL) model, supported by media that incorporated multiple representations (verbal, mathematical, visual/pictorial, and graphic), while the control group was instructed using the PBL model without media support.

### ***Research Procedure***

This study implements a quasi-experimental design with a pretest-posttest nonequivalent control group. The research protocol was formulated to systematically investigate the efficacy of the Problem-Based Learning (PBL) model supported by multirepresentational media on students' comprehension of temperature and phase change concepts. The experimental procedures were conducted in three primary phases: the pretest phase, the treatment implementation phase, and the posttest phase.

During the pretest phase, both the experimental and control groups completed a conceptual understanding assessment comprising multiple-choice questions pertaining to temperature and phase transitions. The objective of this phase was to ascertain students' baseline comprehension and to establish the equivalence of the two groups prior to the intervention.

During treatment implementation, the experimental group was instructed through PBL, a model supported by multirepresentation media, for two weeks. The media focused on four representations: verbal, mathematical, visual/pictorial, and graphical, aiming to boost conceptual comprehension. To be more specific, going through PBL syntax step by step, one would need (1) to participate in problem orientation activities through video analysis and demonstration, (2) organize into groups for problem-solving, (3) explore through directed investigations, (4) present findings, and (5) participate in activities for reinforcing concepts. Simultaneously, teaching in the control group was delivered through the traditional PBL model, without any kind of multirepresentations through media, meaning that instruction was conducted through classroom explanations and group work based on problems provided.

In this posttest phase, both sets of students took a conceptual understanding test, having completed a test of this kind during the pretest phase. The posttest was conducted to note the improvement of concepts gained by students and facilitate an observation of the effectiveness of this PBL model, supported by multirepresentational media, through an analysis of its results concerning the effect on students' concepts.

***Instruments and Data Collection Techniques***

The data for this study were derived from students' pretest and posttest results, gathered via a testing instrument. The instrument used was a multiple-choice test adopted and adapted from Yuberti (2014), covering the topic of temperature and changes in the states of matter. The test had 30 questions designed to assess how well students understood concepts in seven aspects: interpreting, classifying, reflecting, comparing, explaining, exemplifying, and concluding. To keep things consistent and accurately measure how much students' understanding of concepts improved after the learning intervention, both the pretest and posttest used the same set of questions.

Table 1. Test item indicators

An aspect of conceptual understanding	Item indicators	Item number	Number of items
Comparing	Students can translate values between different thermometer scales.	1, 2, 7	3
	Students are able to formulate the notion of specific heat in calculating the final temperature of a mixture	23,25	2
Interpreting	Students are able to display recorded temperature data to analyze the relation between heat transfer and state of matter changes	16, 20, 28, 30	4
	Students are able to formulate the heat equation and Black's principle in solving temperature alterations of an object	6, 13, 14	3
Concluding	Students can use the heat concept to draw conclusions about an occurrence.	3, 4, 8	3
	Students are able to derive and formulate temperature and heat relations to analyze the importance of a situation	19,22,24,29	4
Classifying	Students are able to organize and communicate statements or occurrences related to heat transfer and changes of state.	10,11,12,15,18	5
Exemplifying	Students can recognize occurrences and events related to temperature and heat.	17,21, 26, 27	4
Explaining	Students are able to describe and communicate concepts of heat transfer and state change.	5,9	2

***Data Analysis Technique***

The pretest and posttest data obtained from both the experimental and control classes were analyzed using descriptive and inferential statistical techniques. The data analysis was carried out using SPSS software. The descriptive statistics used to detail the distribution of students' learning outcomes data and to compute and describe the average, standard deviation, minimum, and maximum scores, and to classify the level of students' conceptual understanding.

A test of normality was conducted to determine whether the pretest and posttest data were normally distributed. The Shapiro-Wilk test was used to assess normality in this investigation. In addition, a homogeneity test was conducted to assess the equality of variances between the experimental and control groups. Parametric statistical analyses are used when the data meet the assumptions of normality and homogeneity. On the other hand, nonparametric statistical analyses are employed when these assumptions are not met.

The parametric statistical test employed in this study was the Independent Samples t-test to compare posttest scores between groups, and the Paired Samples t-test to compare pretest and posttest scores within the same group. In the absence of normal distribution and homogeneity, a Mann-Whitney U test was applied for between-group analysis, and a Wilcoxon Signed Rank test for within-group analysis. To assess improvements in students' conceptual understanding, N-Gain analysis was conducted. The N-gain categories were adopted from Hake (1998), as presented in Table 2.

Table 2. Classification of N-Gain percentage intervals and categories

N-Gain percentage (%)	Category
$g < 0.3$	Low
$0.7 > g \geq 0.3$	Medium
$g \geq 0.7$	High

## RESULTS AND DISCUSSION

This study was conducted at SMA Negeri 1 Tumijajar with samples from class XI MIPA. The experimental class employed the PBL model, utilizing multirepresentation media, while the control class followed the same PBL model. To measure students' level of conceptual understanding, pretest data were collected before learning, and posttest data were collected after learning about temperature and changes in the form of matter. The following are quantitative data from the research results presented below.

Table 3. Descriptive analysis results

Class		Minimum	Maximum	Mean	Std.Deviation
Experimental	Pretest	37.00	45.00	40.7500	2.25760
	Posttest	76.00	86.00	81.3125	2.40212
Control	Pretest	45.00	50.00	47.1563	1.46154
	Posttest	70.00	75.00	73.0312	1.25684

Learning activities in the experimental class used the PBL model with the assistance of multirepresentation media, while the control class used the PBL model. Descriptive analysis showed that the average posttest score increased compared to the pretest score in both classes. This increase is consistent with the literature that PBL significantly promotes the development of conceptual understanding (Loyens et al., 2020; Taqwa et al., 2019). To determine whether the increase in conceptual understanding was significant, a more in-depth inferential analysis was conducted. As a preliminary step to ensure the accuracy of the statistical analysis technique selection, a normality test was conducted.

Table 4. Normality test results

Class		Shapiro-Wilk			Category
		Statistic	df	Sig.	
Experimental	Pretest	0.960	32	0.274	normally distributed
	Posttest	0.978	32	0.727	normally distributed
Control	Pretest	0.0935	32	0.055	normally distributed
	Posttest	0.934	32	0.049	non-normally distributed

Based on the results of the normality test, the pretest and posttest data in the experimental class were normally distributed, as indicated by a Sig. Value  $> 0.05$ , while the data in the control class were non-normally distributed. These differences in distribution characteristics determined the choice of statistical tests for each group. The paired t-test was applied to the experimental class, and the Wilcoxon signed-rank test was used in the control class to assess whether there was a significant difference in the mean after treatment, thereby indicating the extent to which the intervention contributed to an increase in conceptual understanding.

Table 5. Paired t-test results and Wilcoxon signed-rank test results

Experimental Class (Paired t-test)	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Mean rank	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
	-40.56250	48.50	.16150	-40.89189	-40.23311	-251.154	31	.000

Control Class (Wilcoxon signed rank test)	Negative rank		Positive rank		Z	Asymp. Sig. (2-tailed)
	N	Mean rank	N	Mean rank		
	0	.00	32	16.50		

Based on the normality test results, the pretest and posttest data in the experimental class were normally distributed; thus, the analysis of score changes was performed using a paired t-test. The test results showed a Sig. (2-tailed) value of 0.000, indicating a significant difference between the pretest and posttest scores. Meanwhile, the data in the control class were not normally distributed, so the change in scores was analyzed using the Wilcoxon signed-rank test. The test results produced an Asymp. Sig. (2-tailed) value of 0.000, indicating a significant change between the pretest and posttest. The dominance of positive ranks (N = 32, mean rank = 16.50) indicates that most students experienced an increase in scores even without the multi-representational media-assisted PBL treatment. However, the nature of the change was more moderate than the increase observed in the experimental class, based on the mean rank values of the two classes.

Table 6. Mann-Whitney U test

	Mean rank	Sum of ranks	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
Experimental	48.50	1 552.00	.000	528.000	-6.905	.000
Control	16.50	528.00				

This test compares the post-test scores of both groups to determine whether one group consistently has higher scores. The analysis results show an Asymp. Sig. (2-tailed) A value of 0.000, indicating a significant difference between the two classes. This difference is reflected in the mean rank, which is much higher in the experimental class (48.50) than in the control class (16.50), indicating that students in the experimental class generally have higher post-test scores than those in the control class. Thus, the Mann-Whitney U test results provide initial indications that the final achievements of the two groups were not at the same level and that the experimental class tended to perform better after the treatment was given. These findings are further reinforced by the normalized gain (N-gain) analysis, which shows the effectiveness of learning improvement in each class, as shown in Table 7.

Table 7. Normalized gain score

Class	Minimum	Maximum	Mean N-gain	Category
Experimental	0.62	0.75	0.68	Medium
Control	0.45	0.52	0.49	Medium

Normalized gain (N-gain) analysis was conducted to evaluate the effectiveness of conceptual understanding improvement after the learning process. Referring to (Hake, 1998) the experimental class obtained an average N-gain of 0.68, which placed it in the medium category and close to the high category threshold. The minimum value of 0.62 and the maximum of 0.75 indicate that most students experienced consistent improvement, with some achieving levels that fall into the high category according to the classification. Meanwhile, the control class showed an average N-gain of 0.49, which also fell within the medium category, with a range of 0.45-0.52. This pattern illustrates that both classes experienced an increase in conceptual understanding, but the degree of improvement differed.

The application of Problem-Based Learning (PBL) improved conceptual understanding in both groups studied. This finding aligns with studies confirming the effectiveness of PBL in promoting conceptual understanding and higher-order thinking skills in science education. However, the greater

improvement in the experimental class indicates that the use of multirepresentational media makes an additional contribution beyond PBL alone. The abstract nature of the concepts of temperature and changes in the state of matter requires visual, mathematical, and graphical representations to help students build more concrete mental models. The use of multirepresentation in PBL learning in the experimental class enabled students to translate between representations more effectively, thereby strengthening their cognitive structures. This aligns with findings (Hahn & Klein, 2023; Munfaridah et al., 2022) showing that representational fluency is an important predictor of success in learning physics.

The distribution of scores in the experimental class tended to be higher and more varied than in the control class. A comparison of the N-gain scores of these two classes provides a more comprehensive picture of the treatment's effectiveness, especially when linked to the findings of the previous Mann-Whitney U test. These findings are in line with studies by Arifiyanti (2019) and Simanjuntak et al. (2021) the application of PBL with multiple representations reduced students' difficulties in understanding physics concepts and improved their representation abilities, with a large effect size. An analysis comparing seven indicators of concept understanding in the experimental and control classes is presented in Figure 1.

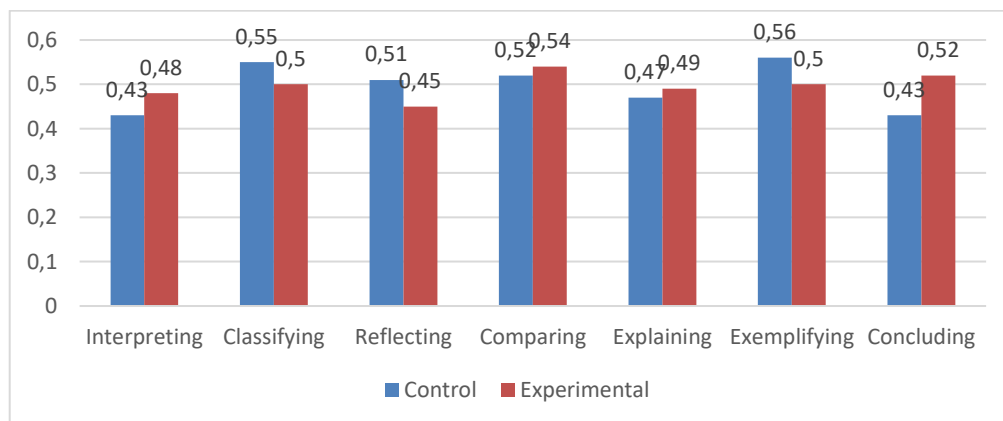


Figure 1. N-gain of conceptual understanding indicators

Analysis of the N-gain graph for the seven concept understanding indicators shows a consistently higher pattern of improvement in the experimental class than in the control class, indicating that the multi-representation-assisted PBL approach specifically strengthens students' concept understanding. The upward pattern in the seven indicators is not homogeneous; the experimental class excels in analysis- and integration-oriented indicators (interpreting, comparing, explaining, concluding), while the control class excels in indicators that are more grouping- or direct application-oriented (classifying, reflecting, exemplifying).

The use of multirepresentation emphasizes inter-representation mapping and cross-format interpretation skills, thereby directly training students to translate concepts from one format to another and assess the appropriateness of meaning. Multirepresentation accelerates knowledge integration, especially when students encounter abstract physics concepts such as temperature and changes of state (Opfermann et al., 2017). The results of the indicators support the claim that multirepresentation media acts as a scaffold that enables students to transform information (Koswojo et al., 2024). Representations support representational translation and mapping between levels of explanation, thereby strengthening students' ability to interpret data, compare alternative representations, construct evidence-based explanations, and draw conceptual conclusions (Ainsworth, 2006; Vogt et al., 2020). Multirepresentational interventions tend to improve representational competence and scientific argumentation skills, which are strongly related to the ability to explain and conclude (Addawiyah et al., 2024; Hahn & Klein, 2023). In other words, the use of multirepresentation requires the same cognitive operations as those involved in interpreting, comparing, explaining, and concluding.

However, the existence of multirepresentational media does not automatically improve all aspects of understanding uniformly. The fact that some other indicators are actually higher in the control class shows that the media is not the only determining factor. In more procedural or recall-based indicators (e.g., identifying or classifying), the pattern of improvement in PBL alone was more

consistent. PBL encourages discussion and exploration of problems, so that students in the control class can develop factual and procedural understanding through intensive interaction without the distraction of complex representations (Marcinauskas et al., 2024; Mardhanuni et al., 2022b). When the number of representations is too high or poorly integrated, it can cause cognitive overload for students as they process information, thereby weakening their focus on procedural details (Cezik Turk, 2022). This may explain why the support of multirepresentational media does not appear to be uniform across all indicators.

The results of this study indicate that the combination of Problem-Based Learning (PBL) with multirepresentational media has substantial implications for physics teaching practices. PBL remains an effective foundation for promoting conceptual understanding, but these findings confirm that reinforcement through multirepresentational media can produce more significant improvements, especially in students' analytical and integrative abilities. The use of media and technology is an important element in improving the effectiveness of PBL (Harahap et al., 2025; Mahardika & Wicaksono, 2023). However, this effectiveness cannot be separated from the influence of other factors outside of instructional design, such as student characteristics, teacher competence, learning environment, and the quality of representation integration itself.

The uneven increase across indicators also shows that multirepresentation is not a universal solution but rather a strategy that requires careful planning to avoid excessive cognitive load. Several limitations in this study need to be noted. One of them is the potential for baseline bias, where differences in pretest scores between the control and experimental classes may affect the scope for improvement. Therefore, further in-depth studies are needed to examine how external factors and multirepresentation integration patterns interact in determining the success of PBL implementation, so that the resulting conceptual understanding is not only quantitatively higher but also more meaningful pedagogically.

## CONCLUSION

This study shows that the use of media-assisted Problem-Based Learning is more effective at improving understanding of temperature and changes in physical state than PBL without media. The most significant improvement occurred in analytical and integrative abilities, especially in the indicators of interpreting, comparing, explaining, and concluding, which shows that multi-representation media strengthen the process of concept construction and translation between representations. However, the improvement was not uniform across all indicators. Procedural and memory-based aspects tended not to benefit significantly, suggesting a potential increase in cognitive load when representations are not optimally integrated. In addition, differences in pretest scores between the two classes may have introduced baseline bias, affecting the magnitude of the improvement.

Further research is recommended, involving a broader sample, a longer intervention duration, and testing a more systematic representation-integration design to minimize cognitive load. Further studies also need to explore the influence of student characteristics and teacher competence on the effectiveness of applying multirepresentation in PBL so that improvements in concept understanding are more consistent and sustainable.

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