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The Effectiveness of Problem-Based Learning Supported by the PhET Virtual Laboratory Simulation in Improving Students' Communication Skills on Temperature and Heat

Mega Indira Teguh Putri*, **Mivtha Citraningrum**, **and Abdul Rachman Tiro**

Master's Program in Pedagogy, Universitas Pendidikan Muhammadiyah Sorong, Jl. KH. Ahmad Dahlan No. 1, Mariat Pantai, Aimas, Sorong Regency, Southwest Papua, Indonesia.

* Corresponding author(s), e-mail: megaindirateguhputri.22@gmail.com

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Abstract:

Communication skills are among the essential competencies required in 21st-century learning and play a crucial role in science education. However, students often experience difficulties in expressing ideas, presenting arguments, and communicating scientific concepts effectively. This study aimed to investigate the effectiveness of Problem-Based Learning (PBL) supported by PhET virtual laboratory simulations in improving students' communication skills on the topic of temperature and heat. The study employed a quantitative approach using a one-group pretest–posttest quasi-experimental design. The participants were 36 eleventh-grade students from a public senior high school in Sorong City, Indonesia. Data were collected through communication skill tests, observation sheets, expert validation instruments, and student response questionnaires. The data were analysed using the Wilcoxon Signed-Rank Test and N-Gain analysis. The results showed a significant improvement in students' communication skills after the implementation of PBL supported by PhET simulations ($Z = -5.244$, $p < 0.001$). The average communication skill score increased from 50.7 on the pretest to 85.5 on the posttest. The N-Gain value of 0.71 indicated a high level of improvement. The greatest improvement was observed in students' ability to explain observation results using physics concepts, while nonverbal communication showed the smallest increase. Student responses toward the learning approach were predominantly positive, particularly regarding the visualization of temperature and heat phenomena and support for scientific communication. These findings suggest that integrating Problem-Based Learning with PhET virtual laboratory simulations is an effective instructional strategy for enhancing students' communication skills in physics learning.

1. Introduction

Advances in industrial technology leading toward the Society 5.0 era require education to adapt and adjust. For educational transformation to successfully navigate the transition toward the Society 5.0 era, the education sector must be able to produce a generation that meets the criteria for 21st-century skills. According to Trilling & Fadel (2009), 21st-century skills consist of three main types of skills, namely (1) life and career skills, (2) learning and innovation skills, and (3) information and technology media skills. This statement is also supported by Barus et al. (2023), who state that 21st-century skills are referred to as the 4Cs, namely (1) creative thinking, (2) critical thinking and problem solving, (3) communication, (4) collaboration.

In addition, according to Nur & Tamam(2024) , rapidly changing global demands require every individual to possess excellent digital skills and critical thinking abilities in order to adapt to increasingly complex global dynamics. Given these global demands, teachers must act as facilitators so that students become more proficient with technology and hone their digital skills. Today's students are individuals living in the 21st century, in an environment heavily influenced by technology and media, as well as widespread access to information across various aspects of life, including education (Nur & Tamam, 2024).

Digital tools can be utilized in the learning process, whether academic or non-academic; in this context, the focus will be on the subject of physics. "Physics is a branch of natural science that discusses and studies natural phenomena through a series of scientific processes" (Ulfa et al., 2022). The physics curriculum covers how everything around us moves, as well as a collection of concepts, facts, theories, and the laws of physics itself. Physics also covers processes, such as activities that demonstrate the laws of physics through observation, experiments, practical work, and investigations to understand various information and even opportunities for the further development of physics concepts and theories in their application to everyday life (Liana et al., 2023).

Furthermore, the purpose of studying physics is for students to be able to understand the principles of this discipline, connect topics, and effectively apply concepts in problem-solving (Sari et al., 2024). Therefore, teachers must innovate in the learning process, one way being through the use of technology, such as conducting laboratory experiments using a virtual laboratory (PhET). The results of previous research by Sietiadi et al. (2015), state that the virtual laboratory simulation program (PhET) can be considered a suite of integrated applications used in the learning process that can develop scientific process skills and other skills that can be developed through this virtual simulation (PhET), namely observing, interpreting, predicting, and communicating.

According to Khoiri et al. (2022) , digitalization has led to changes in various sectors of life, including education, leading to a shift in the skills required in the Society 5.0 era. One of the most essential skills, which plays a crucial role in students' success, is communication skills. Digitalization, including virtual laboratory simulations (PhET), can be utilized in the teaching and learning process and is beneficial not only for cognitive aspects but also for 21st-century skills, namely communication skills. Effective communication encompasses the following aspects: 1) speaking skills, 2) listening skills, and 3) nonverbal skills (Santrock, 2007). Communication skills are essential for all aspects of a profession and are a key component of the "soft skills" required in today's industrial era; therefore, these communication skills do not develop passively during the educational process, but rather require well-planned and targeted efforts and strategies from teachers to facilitate the development of students' communication skills (Osiyanova et al., 2024).

Communication and collaboration skills are essential tools for building shared knowledge because this process involves interactions that facilitate the exchange of ideas and collective problem-solving (Abakah, 2023). According to Hall & Montgomery (2023) these skills are very important because they empower students to express ideas and arguments effectively, appreciate diverse perspectives, and contribute constructively to group discussions. These skills not only strengthen academic learning but also prepare students to interact in a diverse and dynamic society.

According to Tan et al. (2021), there are several communication problems between doctors and patients in the healthcare sector that can lead to an increase in malpractice cases. Similarly, observations conducted by Mayuha et al.(2024), at SMPN 11 Semarang revealed that students lack communication skills; they are not proficient at expressing their opinions, whether in discussion forums or during presentations. At the university level, a study conducted by Mayuha et al. (2024), found that students' science communication skills are not strong enough to effectively transfer the knowledge they have acquired in the classroom. Students often understand concepts but struggle to explain them to others, and learning still tends to focus on the content of the material rather than on how to communicate it scientifically.

The problem-based learning (PBL) model also plays an important role in honing students' communication skills. Through the presentation of real-world situations, students are encouraged to communicate effectively in solving problems, thereby allowing their critical thinking abilities and communication skills to develop optimally (Ningsih et al., 2025). To assess and improve communication skills, teachers must implement appropriate learning models. Widyaputri et al. (2025) state that Problem-Based Learning can present problems in a contextual manner to help students understand physics concepts and laws in a structured way. Good and effective learning occurs when students are actively able to solve problems (Safitri et al., 2022). An interview with a physics teacher at a high school in Pringgabaya Subdistrict, conducted by Hasanah (2025), revealed that "students tend to be passive during lessons, because teachers rarely use the Problem-Based Learning model and often fail to assess students' psychomotor skills." Problem-based learning offers an active approach and encourages students to solve problems and work in groups, as well as develop their communication skills through discussions, presentations, and the resolution of problems that are relevant and contextual to real life (Khoviriza et al., 2024).

The problem-based learning model can be effectively maximized when integrated with the use of learning media, whether simple or technology-based. One alternative form of technology-based learning media that can optimally support learning activities is the use of PhET virtual laboratory simulations, which make it easier for teachers and students to conduct practical work and experiments. Although problem-based learning has clear advantages and benefits, its implementation in Indonesia faces a number of obstacles. According to Arends (2012), PBL is designed to help students develop higher-order thinking skills, communication skills, and the ability to collaborate in groups.

Schools and classrooms in outlying areas are often found to lack sufficient resources and training to support these teaching methods. Similarly, the lack of adequate access to science laboratories in the learning process exacerbates the problem, leaving students with insufficient opportunities to conduct practical work and experiments to verify physics concepts firsthand. The stages of PBL include problem orientation, student organization, investigation, presentation of results, and evaluation of the problem-solving process. During this process, students are actively involved in discussions, arguments, presentations, and providing feedback. These activities directly develop students' communication skills, aligning with the statement 2023) which states that PBL is designed to help students develop higher-order thinking skills, communication skills, and the ability to collaborate in groups.

Furthermore, the integration of PhET into the PBL framework is relevant because interactive simulations provide representations of physical phenomena that can be explored both independently and in a laboratory setting, thereby providing students with a "shared object" to discuss, debate, and explain. Recent findings indicate that PhET is effective as a practical and easily accessible learning tool, and can enhance student engagement and the quality of conceptual understanding, especially when combined with learning strategies that require exploration and problem-solving (Warneri et al., 2024). According to Pamungkas et al. (2024) in the context of temperature and heat, the development of PBL-based tools or worksheets supported by PhET has also been reported to be feasible and has the potential to improve learning outcomes, as students are facilitated to test their predictions and interpret simulation results systematically.This is supported by Siombone et al. (2024) , who note that topics on temperature and heat are relevant for developing scientific communication skills because they encourage students to explain physical phenomena through discussion, argumentation, and presentation.

Research conducted by Indrianingrum et al. (2025) states that teaching the topics of temperature and heat can be used to improve interpersonal communication skills in high school. According to Siombone et al. (2024), topics on temperature and heat are used as a context for physics learning to develop scientific communication and are relevant for training in science communication. Similarly, regarding the use of PhET simulations on temperature and heat, research results show that implementing PhET simulations can improve students' science process skills in these areas—with improvements ranging from moderate to high—and has received positive student feedback. PhET simulations have also been shown to enhance learning, science process skills, and communication skills among students. According to Wieman et al. (2008, cited in Qonita et al., 2025). PhET simulations can improve conceptual understanding through interactive visualization, self-directed exploration, and active student engagement in learning. In the topic of temperature and heat, PhET simulations allow students to interactively observe changes in thermal energy, heat transfer, and temperature changes, thereby supporting discussion and scientific communication.

PhET simulations have also proven effective in improving the quality of physics learning through the visualization of abstract concepts and active student engagement. However, research specifically integrating Problem-Based Learning aided by PhET simulations to enhance students' communication skills in the topics of temperature and heat remains limited. Most previous studies have focused more on improving conceptual understanding or science process skills, while the aspect of communication skills as a 21st-century competency has not been extensively explored in this context. Therefore, this study was conducted to address this gap.

In terms of communication skills, the nature of PBL—which places students in problem-based situations—fosters the need to communicate ideas, construct arguments, and negotiate meaning in group discussions. This is consistent with the latest meta-analysis, which confirms that the implementation of PBL in science education tends to have a positive impact on the improvement of communication skills, although the magnitude of the impact is influenced by task design, the quality of teacher facilitation, and the intensity of group interaction (Khoiri et al., 2024). Therefore, PhET can be positioned not only as a demonstration tool but also as a learning scaffold that enriches the processes of scientific argumentation and communication (e.g., explaining manipulated variables, interpreting patterns, and drawing evidence-based conclusions) during problem-solving (Taufik, 2023).

The PhET Simulations virtual laboratory is highly effective and serves as a solution by providing an interactive platform that is easily accessible and capable of simulating experiments in real time (Khoviriza et al., 2024). Communication skills can be improved through a problem-based learning model integrated with the PhET virtual simulation learning medium. This certainly requires targeted professional training and development to equip educators with the skills needed to effectively implement PBL and virtual laboratories (Khoviriza et al., 2024)

This study integrates the Problem-Based Learning model with PhET virtual laboratory simulations to improve students' communication skills. The PBL model provides activities such as discussion, problem-solving, presentations, and evaluation, while PhET simulations help visualize abstract concepts and facilitate scientific exploration. The integration of these two approaches is expected to improve students' communication skills through investigative activities, group discussions, argumentation, presentation of results, and providing feedback in physics lessons on the topics of temperature and heat.

2. Theoretical Framework

2.1. Students' Communication Skills

Communication skills are among the essential competencies required in 21st-century education. As part of the 4Cs framework—critical thinking, creativity, communication, and collaboration—communication enables students to effectively express ideas, exchange information, construct arguments, and engage in collaborative learning processes. In science education, communication skills play a crucial role because scientific knowledge is developed and shared through discussion, explanation, argumentation, and presentation of evidence-based conclusions. Communication skills can be defined as the ability to convey and receive information effectively through verbal, written, and nonverbal means. According to Santrock (2007), effective communication consists of speaking skills, listening skills, and nonverbal communication skills. Speaking skills involve the ability to express opinions, explain concepts, ask and answer questions, and present information clearly. Listening skills include paying attention to others' ideas, interpreting information accurately, and providing relevant responses. Nonverbal communication refers to the use of gestures, facial expressions, eye contact, and body language that support the communication process.

In the context of physics learning, communication skills are particularly important because students are required not only to understand scientific concepts but also to explain phenomena, interpret data, present arguments, and communicate scientific findings. Effective scientific communication enables students to connect theoretical concepts with empirical evidence and to justify their reasoning logically. Furthermore, communication skills facilitate collaborative problem-solving activities, allowing students to exchange ideas and construct shared understanding through interaction with peers.

Previous studies have demonstrated that communication skills do not develop automatically during classroom instruction. Instead, they require learning environments that provide opportunities for discussion, argumentation, presentation, questioning, and feedback. Therefore, teachers need to implement instructional strategies that actively engage students in communication activities. Learning approaches that emphasize inquiry, collaboration, and problem-solving are considered effective in promoting the development of communication skills because they encourage students to actively participate in the learning process.

In this study, students' communication skills are measured through several indicators adapted from previous communication skill frameworks in science education. These indicators include the ability to express opinions, answer questions, provide responses to others' ideas, present arguments supported by evidence, and communicate the results of discussions or investigations. These indicators represent essential aspects of scientific communication and serve as the basis for evaluating the effectiveness of the implemented learning intervention..

2.2. Problem-Based Learning Supported by the PhET

Problem-Based Learning (PBL) is a student-centered instructional approach that emphasizes learning through the investigation and resolution of real-world problems. The theoretical foundation of PBL is rooted in constructivist learning theory, which views knowledge as actively constructed by learners through interaction with their environment and social experiences. In PBL, students are encouraged to identify problems, formulate hypotheses, gather information, analyse evidence, and propose solutions through collaborative inquiry processes. According to Arends (2012), Problem-Based Learning is designed to help students develop higher-order thinking skills, problem-solving abilities, communication skills, and collaborative competencies. The implementation of PBL generally consists of five stages: problem orientation, organizing students for learning, guiding individual and group investigations, developing and presenting results, and analysing and evaluating the problem-solving process. Through these stages, students become actively involved in discussions, argumentation, information exchange, and presentation activities that promote meaningful learning experiences.

The effectiveness of Problem-Based Learning can be enhanced through the integration of educational technology. One instructional technology that has been widely used in science education is the PhET Interactive Simulations virtual laboratory. Developed by the University of Colorado Boulder, PhET provides interactive computer-based simulations that allow students to explore scientific concepts through virtual experimentation and inquiry. These simulations offer visual representations of abstract scientific phenomena and enable learners to manipulate variables, observe outcomes, and test predictions in a safe and accessible learning environment.

In physics education, PhET simulations are particularly useful for topics that involve abstract concepts and processes that are difficult to observe directly. Through interactive visualization, students can develop conceptual understanding while simultaneously engaging in scientific exploration. Previous studies have reported that PhET simulations improve conceptual understanding, learning engagement, science process skills, and scientific communication. The simulations provide opportunities for students to observe phenomena, interpret data, discuss findings, and construct explanations based on evidence obtained during exploration activities.

The integration of Problem-Based Learning and PhET simulations creates a learning environment that combines collaborative problem-solving with interactive scientific investigation. Within this approach, students use PhET simulations as tools for exploring problems, gathering evidence, and testing explanations while engaging in discussions and collaborative inquiry. Consequently, the combination of PBL and PhET simulations is expected to support not only conceptual understanding but also the development of essential 21st-century skills, particularly communication skills. This integrated approach provides students with opportunities to explain observations, defend arguments, present findings, and communicate scientific ideas based on evidence obtained during problem-solving activities.

2.3. Conceptual Framework of PBL-Assisted PhET for Enhancing Communication Skills

The integration of Problem-Based Learning (PBL) and PhET virtual laboratory simulations provides a learning environment that supports the development of students’ communication skills. PBL is a student-centered instructional model that engages learners in solving authentic problems through discussion, investigation, collaboration, and presentation. Throughout the learning process, students are required to express ideas, explain concepts, present arguments, respond to peers’ opinions, and communicate solutions based on evidence. These activities create meaningful opportunities for the development of communication skills. The theoretical relationship between the stages of PBL, the integration of PhET simulations, and the communication skills developed in this study is presented in Table 1.

Table 1. *Conceptual Relationship between PBL Stages, PhET Integration, and Communication Skills Development*

PBL Stages	Learning Activities	Developed Communication Indicators
Problem Orientation	Students observe phenomena related to temperature and heat through PhET simulations and identify the problems presented by the teacher.	Express opinions and ask questions related to the observed phenomena.
Organizing students	Students discuss in groups to identify problems and develop an investigation plan.	They share ideas, listen to their peers' opinions, and participate in group discussions.
Guiding the investigation	Students explore the concepts of temperature, heat, and thermal energy using PhET simulations and record their observations.	Explaining observations, communicating the information obtained, and using data as the basis for explanations.
Developing and presenting findings	Students compile the results of their investigations and present them to the class.	Presenting information systematically, using clear language, and providing arguments based on data.
Analysing and evaluating	Students reflect on the results of their investigations and provide feedback on other groups' presentations.	Respond to others' opinions, provide feedback, and summarize the results of the discussion both orally and in writing.

The effectiveness of PBL can be further enhanced through the use of PhET virtual laboratory simulations. PhET simulations provide interactive visualizations that enable students to explore scientific phenomena, manipulate variables, observe outcomes, and construct conceptual understanding through inquiry-based activities. In physics learning, particularly on abstract topics such as temperature and heat, PhET simulations help students visualize thermal processes that are difficult to observe directly in conventional classroom settings. From a constructivist perspective, learning occurs when students actively construct knowledge through interaction with their environment and peers. The integration of PBL and PhET supports this process by combining collaborative problem-solving activities with interactive exploration. Students not only investigate scientific phenomena but also communicate their observations, interpretations, and conclusions to others. Consequently, communication becomes an essential component of the learning process rather than merely an outcome of learning. Each stage of the PBL model contributes to the development of communication skills. During problem orientation, students communicate initial ideas and formulate questions related to the presented problem. In the organization and investigation stages, students discuss strategies, exchange information, and explain observations obtained through the PhET simulations. During the presentation stage, students communicate investigation results and provide evidence-based arguments. Finally, in the evaluation stage, students respond to feedback, reflect on their findings, and communicate conclusions both orally and in writing. Therefore, the integration of PBL and PhET simulations is expected to enhance students' communication skills by providing structured opportunities for discussion, scientific argumentation, presentation, and collaborative problem-solving. This approach is particularly relevant to the topic of temperature and heat because students can directly observe thermal phenomena through simulations and communicate their understanding during the problem-solving process.

3. Method

3.1. Research Design

This study employed a quantitative approach with a one-group pretest–posttest quasi-experimental design. This design was used to examine changes in students' communication skills before and after the implementation of Problem-Based Learning (PBL) supported by PhET virtual laboratory simulations. The research design consisted of three stages: pretest, treatment, and posttest. The pretest was administered before the intervention to identify students' initial communication skills. The treatment involved the implementation of PBL supported by PhET simulations on the topic of temperature and heat. After the intervention, a posttest was administered to measure students' communication skills after the learning activities.

3.2. Research Instruments

The instruments used in this study consisted of a communication skills test, a communication skills observation sheet, a learning implementation observation sheet, an expert validation sheet, and a student response questionnaire. The communication skills test was administered as a pretest and posttest to measure students' written communication skills related to temperature and heat. It consisted of multiple-choice and essay items designed to assess students' ability to interpret scientific information, explain physical phenomena, evaluate scientific statements, use data to support explanations, and communicate conclusions. The final multiple-choice communication skills test consisted of ten retained items, which are provided together with their answer key in the Appendix (Table 15).

The essay component consisted of two questions assessing students' ability to explain the relationship between heat and temperature change and construct a written scientific argument. The essay questions are presented in the Appendix (Table 16), while the corresponding scoring rubric is provided in Table 17.

The communication skills observation sheet was used to assess students' speaking, listening, and nonverbal communication during the learning process. Speaking skills included expressing opinions, explaining observation results, and presenting arguments based on data. Listening skills included attending to peers' opinions, providing relevant responses, and summarizing discussion results. Nonverbal communication included demonstrating attention, maintaining eye contact, and using gestures that supported communication. The blueprint of the observation instrument is provided in the Appendix (Table 18), the observation checklist is presented in Table 19, and the scoring rubric is provided in Table 20.

The learning implementation observation sheet was used to examine the extent to which the learning activities followed the stages of PBL supported by PhET simulations. The student response questionnaire was used to collect students' perceptions of the learning process, the ease of using PhET simulations, their engagement during learning, and the contribution of the learning activities to their communication skills. The questionnaire consisted of positive statements using a five-point Likert scale.

3.3. Learning Intervention

The learning intervention integrated the Problem-Based Learning model with PhET virtual laboratory simulations on the topic of temperature and heat. The PhET simulation was used to help students observe temperature changes, heat transfer, and the relationship between heat and temperature through interactive visualization. Through the simulation, students explored temperature and heat phenomena by manipulating variables, observing changes, and discussing the results of their investigation.

The intervention followed the main stages of PBL: problem orientation, organizing students for learning, guiding the investigation, developing and presenting findings, and analysing and evaluating the problem-solving process. In the problem orientation stage, students were introduced to contextual problems related to temperature and heat and observed relevant phenomena through the PhET simulation. In the organizing stage, students worked in groups to identify the problem, formulate initial ideas, and plan their investigation. In the investigation stage, students explored the PhET simulation, manipulated variables, observed changes, and recorded their findings. In the presentation stage, students communicated their investigation results, explained their observations using physics concepts, and presented arguments based on the simulation data. In the evaluation stage, students reflected on their findings, responded to questions or feedback, and summarized the conclusions of the discussion.

Communication skills were integrated into each stage of learning. Students were encouraged to express opinions, ask and answer questions, listen to peers' explanations, provide responses, present arguments, and communicate the results of their investigations both orally and in writing.

3.4. Participants and Data Collection

The study was conducted at the beginning of the even semester of the 2025/2026 academic year at State Senior High School 4 in Sorong City, Indonesia. The participants were 36 eleventh-grade students from Class XI-B. The sample was selected purposively because the class was studying the topic of temperature and heat during the research period and was considered suitable for the implementation of PBL supported by PhET simulations.

Before the study was conducted, permission was obtained from the school and the physics teacher. Students were informed about the learning activities, the purpose of the study, and the use of the data for academic purposes. The research activities were carried out as part of regular physics learning, and students' identities were kept confidential in the reporting of the research findings.

Data collection was conducted in several stages. First, the communication skills pretest was administered to determine students' initial communication skills before the intervention. Second, students participated in physics learning using PBL supported by PhET virtual laboratory simulations on the topic of temperature and heat. During the learning process, students' communication skills and the implementation of the learning activities were observed using observation sheets. Third, after the learning intervention was completed, the communication skills posttest was administered. Finally, students completed a response questionnaire to provide feedback on the learning process and the use of PhET simulations.

3.5. Data Analysis

The data were analysed quantitatively using descriptive and inferential statistics. Descriptive statistics were used to present the mean, highest and lowest scores, frequencies, and percentages for students' communication skill scores, observation results, and student responses. Essay responses were scored using the analytic rubric presented in Table 17, whereas students' observed communication performance was assessed using the four-level rubric presented in Table 20. The scores obtained from these instruments were then converted into percentage scores for descriptive analysis.

Before being used in the study, the instructional materials and research instruments were validated through expert review. The expert review involved five validators, consisting of science education lecturers and physics teachers. The validation focused on content suitability, construct validity, language appropriateness, presentation quality, and the alignment of the learning activities with the PBL syntax and PhET simulation. These aspects were used to evaluate the suitability of the instructional materials, worksheets, and communication skills instruments before they were implemented in the classroom. The aspects assessed in the expert review are presented in Table 2.

Table 2. *Aspects Assessed in the Expert Review Process*

Aspect	Assessment Indicator
Content suitability	Alignment of the material with learning objectives and communication skill indicators.
Construct validity	Alignment of instrument components with communication skill indicators.
Language appropriateness	Clarity, accuracy, and readability of the language used in the instruments and learning materials.
Presentation quality	Systematic organization and presentation of learning materials and simulation-based activities.
Learning appropriateness	Alignment of learning activities with the PBL syntax and PhET simulation integration.

The expert validation results were analysed using Aiken's V index to determine the content validity of the instruments and learning materials. The validators also provided qualitative suggestions for improving the worksheets, communication skill indicators, learning activities, and instructions for using the PhET simulation. The instruments and learning materials were revised based on these suggestions before implementation.

In addition to expert validation, the test instruments were tried out on 36 students outside the research sample. Item validity was examined using Pearson's product-moment correlation at a 5% significance level. Items were considered valid when the calculated correlation coefficient was higher than the r-table value. Instrument reliability was examined using Cronbach's alpha coefficient. Only items that met the validity criteria were used in the pretest and posttest.

The Shapiro–Wilk test was used to inspect the distribution of the pretest and posttest scores. Because the study involved paired data from the same group and the communication skill scores were derived from rubric-based assessments, the Wilcoxon signed-rank test was used as a nonparametric procedure to determine whether there was a significant difference between students' communication skill scores before and after the implementation of PBL supported by PhET simulations. The significance level was set at 0.05.

In addition, normalized gain analysis was conducted to determine the level of improvement in students' communication skills. The N-Gain score was calculated by dividing the difference between the posttest and pretest scores by the difference between the maximum possible score and the pretest score. The N-Gain result was interpreted using the following categories: high improvement when $g \geq 0.70$, moderate improvement when $0.30 \leq g < 0.70$, and low improvement when $g < 0.30$.

Observation sheet and student response questionnaire data were analysed descriptively using percentage scores. The percentage score for each aspect was calculated by dividing the obtained score by the maximum possible score and multiplying the result by 100%, as shown in the formula $percentage\ score = \frac{S_{obt}}{S_{max}} \times 100\%$, where S_{obt} and S_{max} are the obtained and maximum scores, respectively. The percentage results were then used to describe students' communication performance during the learning process and their responses to the implementation of Problem-Based Learning supported by PhET simulations.

4. Result

4.1. Instrument Validity and Reliability

Validity testing was conducted using Pearson's product-moment correlation at a 5% significance level. The results showed that, of the 20 multiple-choice items tested, 10 were deemed valid; and of the 5 open-ended items tested, 2 were deemed valid and used in the study. The reliability test, using Cronbach's alpha, yielded a value of 0.329 for the multiple-choice questions and 0.677 for the essay questions, indicating that the instrument falls into the reliable category (Arikunto, 2014). The results of the item validity and reliability analyses are summarized in Table 3.

Table 3. *Summary of Instrument Validity and Reliability*

Instrument	Initial Items	Retained Items	Retained Item Numbers	Cronbach's Alpha	Interpretation
Multiple-choice test	20	10	1, 2, 3, 5, 6, 8, 9, 12, 13, and 14	0.329	Low internal consistency
Essay test	5	2	1 and 3	0.677	Moderate internal consistency

The results of the multiple-choice and essay-type test instruments that were deemed valid and met the criteria were subsequently used in this study. After the instruments were deemed valid, their reliability was tested. The reliability test results show that both instruments are reliable and suitable for use as research instruments.

4.2. Expert Validation Results

Expert validation was conducted to assess the suitability of the instructional materials and research instruments before they were used in the implementation phase. The assessment covered the appropriateness of the material, the integration of Problem-Based Learning (PBL) syntax with PhET virtual simulations, the suitability of communication skill indicators, the construction of the instruments, and the clarity of the language. In addition to providing quantitative assessments, the validators also offered feedback to inform the refinement of the learning materials and research instruments. The validation results from the five validators indicate that the learning materials and research instruments fall into the "highly valid" category. The Aiken's V results are presented in Table 4. Validated Aspects include content suitability, construct validity, language appropriateness, presentation quality, and learning appropriateness, which are represented as V1 to V5, respectively.

Table 4. *Expert Validation Results Using Aiken's V*

Validator	V1	V2	V3	V4	V5
Expert 1	5	5	5	4	5
Expert 2	5	5	5	5	5
Expert 3	5	4	5	5	5
Expert 4	4	5	5	5	5
Expert 5	5	5	4	5	4
Aiken's V	**0.95**	**0.95**	**0.95**	**0.95**	**0.95**

Based on the expert validation results presented in Table 4, all assessed aspects obtained an Aiken's V value of 0.95. This value indicates that all components of the instructional materials and research instruments fall into the "highly valid" category because they have values above 0.80. These results indicate that the developed materials meet the criteria for suitability for use in the learning process and for research data collection.

Although all aspects were rated as highly valid, the validators still offered several suggestions for improving the tool. The feedback primarily focused on strengthening learning activities that support students' communication skills, improving the clarity of instructions for using the PhET virtual simulation in the worksheets, and refining the wording of the instrument to make it more operational and easier to understand. In addition, the validators suggested that each stage of learning provide students with more equal opportunities to express their opinions, ask questions, offer feedback, and present the results of discussions. Revisions were made by optimizing learning activities that encourage student verbal interaction, clarifying instructions for using the PhET simulations, and refining the wording of the instrument to make it more operational and easier to understand. The revisions made in response to these suggestions are summarized in Table 5.

Table 5. *Revisions Based on Expert Recommendations*

Components	Before Revision	Validator's Suggestions	After Revision
Worksheet	Students observe the simulation	Add a communication activity	Students observe the simulation and then explain their observations to the group
Investigation Syntax	Focus on concept exploration	Add data-based discussions	Students discuss the results of their exploration and construct arguments based on the simulation data
Presentation of Results	Group presentation	Give all members a chance to speak	Each group member presents part of the investigation results
Communication Tools	The wording of some indicators is unclear	Revise the wording	Formulate the indicators to be more specific and operational

Following the expert review, revisions were made to the worksheet in accordance with the validators' suggestions. These revisions focused on improving the clarity of instructions, strengthening communication-oriented activities, and aligning the learning tasks more closely with the PBL stages. Figure 1 presents an example of the revised worksheet used in the study.

Sintaks 1. Orientasi terhadap Masalah

1. Akseslah Lab virtual dan memilih eksperimen *energy forms and changes* pada link https://phet.colorado.edu/sims/html/energy-forms-and-changes/latest/energy-forms-and-changes_all.html .
2. Perhatikan ilustrasi/gambar fenomena suhu dan kalor.

Diskusikan bersama kelompokmu:
1. Mengapa suhu air dapat berubah?
2. Apa yang menyebabkan suhu suatu benda naik atau turun?
3. Tuliskan prediksi kelompokmu sebelum melakukan investigasi menggunakan simulasi PhET.

Indikator komunikasi:
• Mengemukakan pendapat.
• Menyampaikan prediksi secara lisan.

Figure 1. *Screenshot of the student worksheet Syntax 1: Problem Orientation*

4.3. Pretest and posttest Results

The descriptive statistics for students' communication skill scores before and after the intervention are presented in Table 6.

Table 6. *Pretest and Posttest Results for the Experimental Class*

Measurement	N	Mean	Minimum	Maximum
Pretest	36	50.7	42	60
Posttest	36	85.5	82	89

The mean communication skill score increased from 50.7 on the pretest to 85.5 on the posttest, representing a descriptive increase of 34.8 points. The minimum score increased from 42 to 82, while the maximum score increased from 60 to 89.

4.4. Results of the Normality Test, Wilcoxon Test, and N-Gain

The Shapiro–Wilk test was used to inspect the distribution of the pretest and posttest scores. The pretest and posttest significance values were 0.213 and 0.984, respectively. Both values exceeded 0.05, indicating no statistically significant departure from normality. Nevertheless, the Wilcoxon signed-rank test was retained because the communication skill scores were derived from rubric-based assessments and were treated nonparametrically in the analysis. The results of the Wilcoxon signed-rank test and normalized gain analysis are presented in Table 7.

Table 7. *Wilcoxon Signed-Rank and N-Gain Results*

Analysis	Statistic	Value	Interpretation
Shapiro–Wilk test: pretest	p	0.213	No significant departure from normality
Shapiro–Wilk test: posttest	p	0.984	No significant departure from normality
Wilcoxon signed-rank test	Z	−5.244	—
Wilcoxon signed-rank test	p	< 0.001	Significant pretest–posttest difference
Normalized gain	g	0.71	High improvement

The Wilcoxon signed-rank test showed a statistically significant difference between the pretest and posttest scores, ($Z=-5.244$), ($p<0.001$). Thus, students' communication skill scores were significantly higher after the implementation of PBL supported by PhET simulations. The normalized gain of 0.71 was categorized as high, indicating a substantial increase relative to the maximum achievable improvement. Descriptive changes in the communication skill indicators are presented in Table 8. These values describe the magnitude of change for each indicator and should not be interpreted as separate inferential test results.

Table 8. *Descriptive Pretest–Posttest Scores by Communication Skill Indicator*

Aspect	Indicator	Pre-test	Post-test	Improvement
Speaking Skills	Expressing opinions clearly	48.6	88.9	40.3
	Explaining observation results using physics concepts	44.4	87.5	43.1
	Presenting arguments based on data	42.1	84.7	42.6
Listening Skills	Paying attention to classmates' opinions	58.3	88.9	30.6
	Providing relevant responses	46.5	83.3	36.8
	Summarizing the results of a discussion	49.3	84.7	35.4
Nonverbal Communication	Showing attention during the discussion	62.5	86.1	23.6
	Maintaining eye contact while speaking	60.4	84.7	24.3
	Using gestures that support communication	58.3	81.9	23.6
mean of the nine indicator-level scores		**52.3**	**85.6**	**33.3**

All indicator scores were descriptively higher after the intervention. The largest change occurred in explaining observation results using physics concepts, which increased by 43.1 points. The smallest changes occurred in showing attention during discussions and using gestures that supported communication, each of which increased by 23.6 points.

4.5. Communication Skills Observation Results

Students' communication performance during the learning activities was assessed using an observation sheet covering speaking, listening, and nonverbal communication. The frequency distribution of the observation scores is presented in Table 9.

Table 9. *Distribution of Communication Skill Observation Scores*

Category	Interval	Frequency (F)	Percentage (%)
Very Good	86–100	20	56%
Good	76–85	16	44%
Fair	60–75	0	0%
Insufficient	55–59	0	0%
Very Low	≤ 54	0	0%
Total		**36**	**100%**

The observation results showed that 20 students, representing 56% of the participants, were categorized as demonstrating very good communication performance. The remaining 16 students, representing 44%, were categorized as demonstrating good communication performance. No students were classified in the fair, insufficient, or very low categories. These findings provide descriptive evidence of favorable communication performance during the implementation of PBL supported by PhET simulations.

4.6. Student Response Results

Students' responses to the implementation of the Problem-Based Learning (PBL) model aided by PhET virtual simulations were obtained through a questionnaire administered after the entire learning sequence was completed. In general, students responded positively to the learning activities that had taken place. These responses suggest that students perceived the PhET simulations as helpful for understanding temperature and heat concepts and for supporting their engagement during the learning activities. The results are summarized by aspect in Table 10. Students generally reported favorable perceptions of the learning activities. The highest mean response was obtained for the visualization of temperature and heat phenomena, at 92.8%. Responses concerning support for scientific communication and group interaction were also high, at 88.3% and 85.7%, respectively. The lowest mean response concerned students' understanding of relationships among variables, at 76.9%. At the item level, the highest response was obtained for the statement that PhET simulations helped students understand temperature and heat phenomena more clearly, at 94.4%.

Table 10. *Summary of Student Responses by Aspect*

No	Statement	Aspect	Response (%)
1	The PhET simulation helped me understand the phenomena of temperature and heat more clearly.	Visualization of Phenomena	94.4
2	PhET simulations make it easier for me to observe changes in temperature when an object is heated or cooled.	Visualization of Phenomena	91.7
3	The PhET simulation interface makes the concepts of temperature and heat easier to understand.	Visualization of Phenomena	92.4
4	I find it easier to explain my observations after using the PhET simulation.	Scientific Communication	89.8
5	PhET simulations help me express my opinions during group discussions.	Scientific Communication	88.0
6	PhET simulations help me answer questions asked by my friends or teachers.	Scientific Communication	87.0
7	PhET-assisted PBL learning makes me more active in discussions.	Group Interaction	86.1
8	I felt more confident expressing my opinions during the lesson.	Group Interaction	85.2
9	I found it easier to understand the relationship between heat and temperature changes after using the PhET simulation.	Conceptual Understanding	82.4
10	I can explain the relationship between various variables in the topics of temperature and heat after using the PhET simulation.	Understanding of Variables	77.8
11	I can analyze the effect of a change in one variable on another variable in the context of temperature and heat.	Understanding Variables	75.9
12	Overall, PBL learning supported by PhET simulations helped me understand the topics of temperature and heat.	General Response	89.6

The lowest response was obtained for the statement concerning students' ability to analyze the effect of a change in one variable on another, at 75.9%. These findings indicate that students perceived the visualization and communication functions of the simulations more favorably than activities requiring analysis of relationships among variables. Figure 2 presents the use of the PhET "Energy Forms and Changes" simulation during the investigation stage. Students used the simulation to observe temperature changes and heat transfer, discuss their observations with group members, and prepare explanations of their investigation results for presentation to the class.

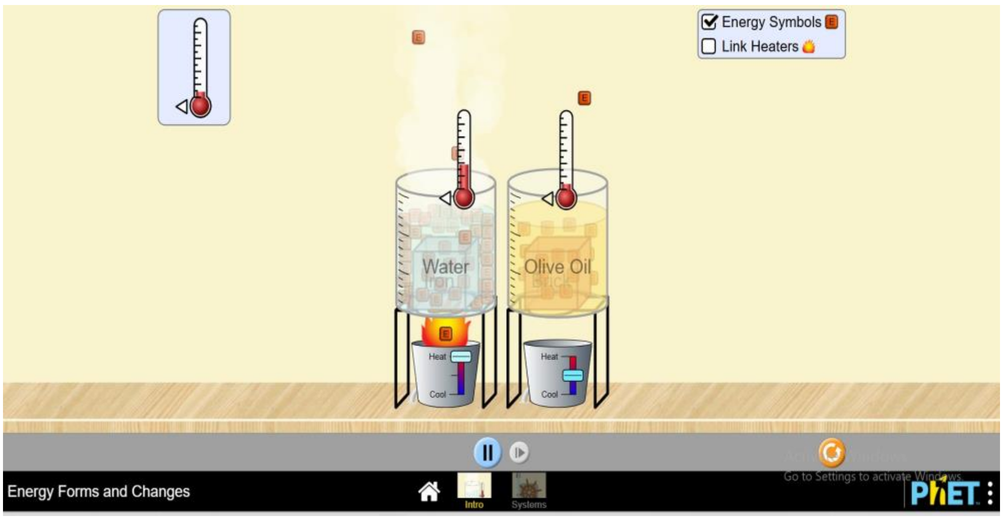

Figure 2. *Screenshot of the PhET Simulation During the Lesson on Temperature and Heat*

5. Discussion

5.1. Interpretation of Findings

The improvement in students' communication skills after participating in Problem-Based Learning (PBL) supported by PhET virtual simulations indicates that integrating problem-solving activities with visual exploration of phenomena can foster scientific communication. In this study, students did not merely receive information passively; they were actively engaged in observing phenomena, discussing, expressing opinions, explaining their observations, and presenting their investigation findings. These activities align with the characteristics of PBL, which places students at the centre of learning through inquiry and communication during problem-solving (Arends, 2012).

The highest improvement was found in the indicator of explaining observational results using physics concepts. This finding indicates that the use of PhET simulations provides strong support for students' ability to connect their observations with the concepts of temperature and heat. During the investigative activities, students directly observed changes in temperature, the transfer of thermal energy, and changes in the system's state through the simulations, and then explained these observations during group discussions and class presentations. This aligns with the view of Wieman et al. (2008), who state that PhET simulations help students build conceptual understanding through interactive visualization, thereby enabling them to communicate scientific concepts more clearly.

These findings are consistent with the studies by Azhari et al., (2025) and Liana et al. (2023) which show that the integration of PBL and PhET enhances students' engagement, interaction, and communication skills in physics learning. Additionally, Hasbullah et al., (2025) report that the use of PhET based on multiple representations improves students' verbal representation skills, which supports the development of scientific communication.

Conversely, the aspect that received relatively lower responses was related to the ability to explain the relationships between variables in the temperature and heat material. Although still in the "good" category, these results indicate that students still experience difficulties in understanding the quantitative relationships between heat, mass, specific heat, and temperature changes. This occurs because students' understanding of the various variables in the temperature and heat material is still limited. Students tend to find it easier to understand phenomena that can be observed visually than to explain the mathematical relationships and cause-and-effect connections among the variables involved. This finding aligns with the research by Siombone et al. (2024), which states that visualization aids initial conceptual understanding, but analysing variable relationships requires more in-depth reasoning practice.

When examined from the perspective of the implemented instructional design, the strongest component was found in the investigation stage using PhET simulations. At this stage, students had the same objects of observation, so discussions were more focused, and the arguments presented were based on data from the simulations. This finding supports the results of the research by Khoviriza et al. (2024), which showed that the integration of PBL and investigative activities can enhance scientific communication through the processes of argumentation and the exchange of ideas. However, nonverbal communication showed a relatively smaller improvement compared to other indicators. These results suggest that skills such as eye contact, gestures, and facial expressions during communication require a longer period of practice and therefore cannot develop optimally through just a few learning sessions.

5.2. Implications

The findings of this study imply that PhET virtual simulations not only serve as a medium for visualizing physics concepts but can also be used as a tool to develop students' communication skills. The integration of PBL and PhET provides students with the opportunity to observe phenomena, interpret data, present arguments, and defend their opinions based on evidence obtained during the investigation. Therefore, this approach can serve as a relevant learning alternative for developing communication skills—one of the 21st-century competencies—particularly in abstract physics topics such as temperature and heat.

5.3. Limitation

Several limitations should be considered when interpreting the findings of this study. First, the study employed a one-group pretest–posttest design without a control group, limiting the ability to attribute improvements in students' communication skills solely to the implementation of PBL supported by PhET simulations. Other factors, such as prior learning experiences and classroom dynamics, may also have contributed to the observed outcomes. Second, the study involved a relatively small sample of 36 students from a single senior high school, which may limit the generalizability of the findings. Third, the intervention was conducted only on the topic of temperature and heat; therefore, the effectiveness of PBL-assisted PhET learning may differ across other physics topics. Finally, although communication skills were assessed using tests and classroom observations supported by validated rubrics, some degree of subjectivity may have remained in the evaluation process. Future studies are recommended to employ larger samples, comparison groups, longer intervention periods, and broader physics content to provide more comprehensive evidence of the effectiveness of this instructional approach.

6. Conclusion

Based on the research findings, the integration of the Problem-Based Learning (PBL) instructional design with PhET virtual simulations was successfully implemented to develop students' communication skills on the topics of temperature and heat. The structured PBL syntax empowered students to actively express opinions, present data-driven arguments, and scientifically communicate their investigative findings. Quantitative analyses demonstrated a significant positive impact on these skills, with the Wilcoxon Signed-Rank Test confirming a significant difference between pretest and posttest scores and an overall N-Gain of 0.71 indicating a high level of improvement. Notably, the most substantial gain occurred in the students' ability to explain observational results using physics concepts, whereas nonverbal communication showed the smallest improvement. Supported by highly positive student responses to the interactive visualizations, these findings confirm that the PBL-PhET integration is a robust pedagogical alternative for fostering 21st-century communication skills in abstract physics topics. To further validate this model, future research should apply this instructional design to other complex physics domains and involve larger sample sizes across diverse educational settings.

Author Contributions

Mega Indira Teguh Putri: conceptualization, methodology, data collection, data analysis, writing the original draft. **Mivtha Citraningrum:** research design, validation of instruments, supervision, and review & editing of the manuscript. **Abdul Rahman Tiro:** statistical analysis, interpretation of results, and manuscript review.

Ethical Statement

This study involved student participants and was conducted in accordance with ethical principles for educational research. Permission to conduct the study was obtained from the school administration and the relevant physics teacher. The participants were informed about the purpose and procedures of the study, the voluntary nature of their participation, and the use of the collected data for research purposes.

Informed consent was obtained from the participants before data collection. Participants' identities and personal information were kept confidential, and the findings were reported anonymously.

Declaration of AI use

During the preparation of this manuscript, the authors used ChatGPT to assist with English-language translation, grammatical correction, clarity, and text organization. All AI-assisted content was critically reviewed, revised, and verified by the authors, who take full responsibility for the accuracy and integrity of the manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article, either financial or non-financial.

Supplementary Materials and Data Availability

The communication skills test, essay-scoring rubric, and classroom observation instruments are provided in Appendices. Additional research materials and supporting data are available from the corresponding author upon reasonable request.

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Appendix. Research Instruments

Table 15. *Final Multiple-Choice Communication Skills Test Items*

<table>
<tr><th>No.</th><th>Indicators</th><th>Questions</th><th>Answer</th></tr>
<tr><td>1</td><td>Interpret scientific information presented in narrative form (C2)</td><td>A student observed that when water is heated, its temperature rises gradually. After discussing this with his group, the student explained that the temperature increase occurs because the water absorbs thermal energy from a heat source. The statement that best supports the student’s opinion is....
A. Water turns into a new substance when heated
B. Water absorbs energy, causing the kinetic energy of its particles to increase
C. The mass of the water increases during the heating process
D. Heat and temperature are the same quantity
E. Heating causes the number of water particles to increase</td><td>B</td></tr>
<tr><td>2</td><td>Selecting the most appropriate information to explain a phenomenon (C2)</td><td>Consider the following observation: "The temperature of the water in the glass rose from 25°C to 50°C after being heated for several minutes." The most appropriate information to explain these observation results is....
A. The water released heat into the environment
B. The water lost thermal energy
C. The water absorbs heat, causing its temperature to rise
D. The density of the water becomes zero
E. Heat turns into mass</td><td>C</td></tr>
<tr><td>3</td><td>Identify the validity of scientific arguments (C4)</td><td>During a group discussion, a student stated: "Metal feels cooler than wood because metal has a lower temperature." The most appropriate response is....
A. The statement is true because metal always has a lower temperature
B. The statement is true because metal contains more heat
C. The statement is not entirely correct because metal and wood can have the same temperature
D. The statement is true because metal has a greater mass
E. The statement is correct because only metals possess heat</td><td>C</td></tr>
<tr><td>4</td><td>Using data to support scientific communication (C4)</td><td>The experimental data show:
<table><tr><th>Time (minutes)</th><th>Water Temperature (°C)</th></tr><tr><td>0</td><td>30</td></tr><tr><td>2</td><td>40</td></tr><tr><td>4</td><td>50</td></tr><tr><td>6</td><td>60</td></tr></table>The conclusion that best fits the data is....
A. The water temperature decreases over time
B. Heat does not affect the water temperature
C. The water’s temperature increases during heating
D. The mass of the water increases during heating
E. The water turns into ice</td><td>C</td></tr>
<tr><td>5</td><td>Selecting clear and logical scientific statements (C3)</td><td>The statement that best explains the relationship between heat and temperature is....
A. Heat is a measure of an object’s degree of warmth
B. Temperature is the energy that is transferred
C. Heat absorbed by an object can cause a change in temperature
D. Heat and temperature have the same unit
E. Heat flows from a hot object to a cold object</td><td>C</td></tr>
<tr><td>6</td><td>Interpret the results of written communication (C3)</td><td>A student wrote the following conclusion: "When water is cooled, thermal energy is transferred from the water to the environment, causing the water’s temperature to decrease." This conclusion indicates that the student understands....
A. The relationship between heat and temperature change
B. Changes in the mass of an object</td><td>A</td></tr>
</table>

No.	Indicators	Questions	Answer
		C. Changes in the volume of a substance D. Changes in the color of a substance E. Newton's laws	
7	Evaluating information provided by others (C4)	In a presentation, a group stated: "The more heat that is added to an object, the higher its temperature." That statement is true if.... A. There is no change in state B. The mass of the object becomes zero C. The object's initial temperature is 0°C D. The object's specific heat is zero E. The pressure of the object remains constant	A
8	Identify important information in scientific communication (C2)	Consider the following statement: 1. Heat is energy that is transferred. 2. Temperature indicates the degree of heat of an object. 3. Heat and temperature have the same meaning. The correct information is.... A. Only 1 B. 2 only C. 1 and 2 D. 2 and 3 E. 1, 2, and 3	C
9	Interpreting observation results (C3)	In the PhET simulation, it can be seen that the water temperature increases when the "heat" button is pressed. The most appropriate interpretation is.... A. The water loses energy B. The water receives heat from a heat source C. The mass of the water decreases D. Heat is converted into temperature E. The number of particles increases	B
10	Determine the conclusion that corresponds to the observation results (C4)	Based on the observations and discussion, students conclude that heat affects changes in an object's temperature. This conclusion is drawn because.... A. The temperature of an object changes after it absorbs or releases heat B. Heat causes an object to lose mass C. Heat causes an object to change color D. Temperature and heat are the same quantity E. Heat is not related to energy	A

Table 16. *Essay Questions for Assessing Communication Skills*

No	Indicator	Item Indicator	Question
1	Explaining scientific information in writing (C4)	Explaining the relationship between heat and temperature change based on observation results	During a learning activity using a PhET simulation, students observe that the water temperature increases when the heat control is activated and decreases when the cool control is activated. Explain the relationship between heat and temperature change based on these observations. Present your answer coherently and use appropriate physics concepts.
2	Presenting a scientific argument in writing (C5)	Constructing an argument in response to a statement based on physics concepts	During a group discussion, one student states, "Heat and temperature are the same physical quantity because both are related to hotness." Do you agree with this statement? Explain your reasoning using the correct concepts of heat and temperature, and provide an argument that supports your answer.

Table 17. *Scoring Rubric for the Communication Skills Essay Questions*

Score	Assessment Criteria
4	The response is highly complete, uses accurate physics concepts, presents a logical argument, and is expressed clearly and coherently.

3	The response is reasonably complete, most physics concepts are correct, the argument is reasonably logical, and the language is sufficiently clear.
2	The response is incomplete, contains conceptual errors, presents a weak argument, and lacks coherence.
1	The response is highly incomplete, uses inaccurate physics concepts, and presents an unclear argument.
0	No response is provided.

Table 18. *Blueprint of the Observation Instrument*

No	Aspect	Observed Indicator
1	Speaking skills	Expressing opinions during discussions
2	Speaking skills	Explaining observation results using physics concepts
3	Speaking skills	Presenting arguments based on simulation data
4	Listening skills	Listening attentively to peers' opinions
5	Listening skills	Responding to peers' opinions
6	Listening skills	Summarizing discussion results
7	Nonverbal communication	Demonstrating attention during discussions
8	Nonverbal communication	Maintaining eye contact while speaking
9	Nonverbal communication	Using gestures that support communication

Table 19. *Observation Sheet (Checklist)*

No	Observed Indicator	1	2	3	4
1	Expressing opinions during group discussions	☐	☐	☐	☐
2	Explaining PhET simulation observations using the concepts of temperature and heat	☐	☐	☐	☐
3	Presenting arguments based on observational data	☐	☐	☐	☐
4	Listening to peers' explanations without interrupting	☐	☐	☐	☐
5	Responding to questions from peers or the teacher	☐	☐	☐	☐
6	Clearly communicating the conclusions of the discussion	☐	☐	☐	☐
7	Paying attention during discussions and presentations	☐	☐	☐	☐
8	Maintaining eye contact while speaking or presenting	☐	☐	☐	☐
9	Using facial expressions and gestures that support communication	☐	☐	☐	☐

Table 20. *Observation-scoring rubric*

Indicator	Score 4	Score 3	Score 2	Score 1
Expressing opinions	Actively expresses ideas clearly and confidently	Expresses opinions but not consistently	Expresses an opinion only when prompted	Does not express an opinion
Explaining observation results	Explains the results accurately using physics concepts	Provides a mostly accurate explanation	Provides an incomplete explanation	Is unable to provide an explanation
Presenting arguments	Presents a logical argument supported by data	Presents a reasonably logical argument	Presents an argument with insufficient data support	Is unable to present an argument
Listening to peers' opinions	Always listens attentively	Frequently listens attentively	Occasionally pays attention	Does not pay attention
Providing responses	Provides accurate and relevant responses	Provides reasonably relevant responses	Provides less appropriate responses	Does not provide a response
Summarizing discussion results	Provides a complete conclusion consistent with the	Provides a reasonably accurate conclusion	Provides an incomplete conclusion	Is unable to draw a conclusion
Demonstrating attention	Remains focused throughout the learning activities	Remains reasonably focused	Shows limited focus	Does not pay attention
Maintaining eye contact	Maintains very good eye contact while speaking	Maintains reasonably good eye contact	Rarely maintains eye contact	Does not maintain eye contact while speaking

Using gestures	Uses gestures that effectively support communication	Uses reasonably appropriate gestures	Uses gestures that provide limited support for communication	Does not use gestures to support communication