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Design and Evaluation of PBL-STEM Based Electronic Worksheets Supported by PhET Virtual Physics Labs to Enhance Science Literacy

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Abstract: This study aims to produce PBL-STEM-based Student Worksheet Electronics assisted by PhET simulation on the topic of temperature and heat that is feasible and able to improve science literacy in a limited way by reviewing the results of N-Gain score analysis. The subjects in this study were students of class VII C SMP Muhammadiyah 3 Depok Sleman totaling 30 students, with 17 male and 13 female students. The research model used in this research is the 4-D (Four D) development model which consists of four stages, namely define, design, develop, and disseminate. The instruments in this study were interview guidelines, validation sheets, and students' pre-test and post-test questionnaires. Analysis of feasibility data was obtained through a validation questionnaire validated by three expert validators, while the improvement of science literacy was obtained through the results of limited trials. The data was obtained through the results of the pre-test and post-test given to students before the application of PBL-STEM-based Electronic Student Worksheets assisted by PhET simulation and after the application of PBL-STEM-based Electronic Student Worksheets assisted by PhET simulation. The validity results of this study obtained an average assessment score from the three expert validators of 93% with very valid criteria so that the PBL-STEM-based Electronic Student Worksheet aided by PhET simulation can be applied to science learning. The results of improving science literacy through limited testing of PBL-STEM-based Electronic Student Worksheets assisted by PhET simulation as an effect caused by the use of development products are creating a problem solution of 0.78, identifying scientific issues of 0.74, explaining scientific phenomena of 0.72 and using scientific evidance of 0.71. Overall, the increase obtained for each indicator is categorized as high, resulting in an average N-Gain value of 0.71 with high value criteria so that it can improve students' science literacy. Based on the results of the study, it is concluded that the development of PBL-STEM-based Electronic Student Worksheets assisted by PhET simulation is valid and can improve students' scientific literacy through limited tests with high N-Gain categories in each science literacy indicator.

Keywords: elektronic student worksheet, problem based learning, STEM, science literacy.

▪ INTRODUCTION

Science literacy is the ability to understand, use, and communicate science concepts in the context of everyday life. Science literacy includes the ability to interpret scientific information, evaluate arguments based on evidence and make decisions based on an understanding of the scientific process (Holbrook et al., 2009). PISA 2015 strengthens the definition of science literacy with the statement that it is seen as the ability of citizens to understand and consider science phenomena and concepts. Science literacy is expected to give a person the ability to ask, find, or determine answers to questions that arise from their curiosity about everything. So that students can solve problems scientifically, their curiosity must be directed towards scientific thinking and scientific attitudes (OECD, 2023). This era of globalization in science learning should be able to form science literacy, which has competence in scientific thinking as an effort to solve individual

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problems and issues in society so that it can play a role in becoming better human resources (Yang et al., 2024). The implementation of science concepts is needed in the real world that is rapidly changing. Therefore, science literacy is one of the keys in facing the challenges of the 21st century. Science literacy at this time can be a guideline that must be owned by every person, both in everyday life and in the world of work. A science literate person can utilize the scientific information they have in solving problems or issues in real life (Kolstø, 2001; Nuangchalerm, 2010).

According to the results of the Program for International Student Assessment (PISA) analysis conducted by the Organization of Economic Cooperation and Development (OECD, 2023), the quality of education in Indonesia is ranked 74 out of 79 participating countries in the field of science literacy. This position shows that Indonesia has challenges in improving the quality of science education at the international level. Furthermore, El Islami & Nuangchalerm (2020) in their comparative research found that Indonesian students are indicated to have low science literacy skills so that learning is needed that can train students' science literacy to improve. Good learner science literacy is needed to solve problems in everyday life in applying the sciences used in the learner's environment.

Information and communication technology has developed rapidly. The Industrial Revolution 4.0 has often been discussed, where technology is used in various aspects of life and greatly affects human life. Education, as one of the important aspects of human life, also needs to keep up with this technological development by making students actors in the technology that is currently developing (Syynimaa, 2018). Quality education is one of the keys to success to produce students as actors of technological development. The concept of education needs to be changed from teacher-centered teaching and learning to learner-centered. Educators no longer transfer as much knowledge as possible but facilitate learners to develop their knowledge by utilizing current technology (Heggart & Yoo, 2018). Learners are expected to develop their knowledge by utilizing available technology. The development of technology, especially internet technology, has expanded the scope of information, such as access to digital learning resources and interaction with teachers and among learners (Martín-Blas & Serrano-Fernández, 2009). The utilization of internet technology in learning and e-learning facilitates learners and teachers without space and time constraints (Culliton et al., 2018). Through e-learning media, a teacher presents various learning facilities to support online learning, such as PhET virtual simulations (Rahmawati et al., 2020). Learning facilities can be in the form of providing quality teaching materials and can be easily accessed by students(Baumert et al., 2010). Therefore, educators also need to improve their ability to present teaching materials that utilize technology and are able to improve science literacy skills (Hart Barnett & Lee, 2003). One of the efforts to assist students in learning is by providing electronic student worksheets (e-worksheets) to guide them in learning (Imanzha & Rosana, 2024). The E-LKPD is integrated into online learning, or e-learning, so that learners can access it anytime and anywhere. The worksheets designed are expected to have a positive impact on learners' understanding and skills. The use of elektronic worksheets can also be optimized if integrated with the Problem-Based Learning (PBL) learning model because it can increase learner engagement, support active learning, and improve concept understanding and stronger analytical thinking (Odell et al., 2019; Yew & Goh, 2016). The use of the PBL learning model helps in improving science literacy

skills in secondary-level students (Lawless et al., 2018). Electronic worksheets integrated with PBL can develop learners' science literacy, analytical, and problem-solving skills in a more structured and in-depth way (Savery, 2006).

Problem-Based Learning (PBL) models and approaches integrated with Science, Technology, Engineering, and Mathematics (STEM) have an important role in improving science literacy. The basic concepts of science and the problem-solving process in PBL can be linked to STEM. Integrating STEM in learning, we can use activities designed with engineering elements (Su, 2022). In PBL-STEM learning, students are critically, creatively, and innovatively challenged to solve real-world problems through collaborative teamwork (Firman, 2016). PBL-STEM can encourage students to actively use aspects of science and engineering and gain a deep understanding of math and science to improve skills and experience in using their knowledge directly (Mardatillah & Kristayulita, 2024). The integration of all STEM aspects in the learning process makes knowledge more meaningful as students are involved in the product design process, which allows them to collect, organize, and communicate their findings about the concepts (Parno et al., 2020). Learners construct the application of concepts in STEM learning products through the knowledge they acquire. It builds learners' motivation to learn more and be creative in science learning (Guthrie et al., 2000). Additionally, STEM integration motivates students to pursue their future aspirations and dream jobs, while focusing on science and math (She et al., 2018; Stohlmann, M., Moore, T. J., & Roehrig, 2012).

Research has proven that integrating PBL-STEM into teaching materials enhances students' critical thinking and collaboration skills (Irawan et al., 2024; Puspita et al., 2024). The implementation of PBL-STEM in science learning has been proven to be able to build knowledge construction from various fields and prepare students to face the real world according to the challenges of the 21st century (Navy & Kaya, 2020). In terms of learning conditions in the classroom, students become more active when using worksheets integrated with PBL-STEM (Dotimineli & Mawardi, 2021). Implementing learning through PBL-STEM can improve students' science literacy skills compared to PBL models without the role of STEM and conventional learning (Lee et al., 2019; Parno et al., 2020). Electronic worksheets that contain learning models with PhET virtual simulations in the PBL model framework can build an active and conducive classroom atmosphere (Arifa et al., 2023). This fact presents an opportunity for the integration of PBL-STEM into student worksheets, with the aid of PhET simulations, to effectively enhance science literacy skills and enhance the teaching and learning process in the classroom.

Based on the various problem studies that have been described, the researchers are interested in conducting a product development study of PBL-STEM-based electronic student worksheets assisted by PhET simulation on the topic of temperature and heat. The developed products incorporate PhET virtual lab technology, presenting them online for optimal student learning anytime and anywhere. The selected subject matter is temperature and heat because it requires a deeper understanding of the basic principles of physics, which are abstract and often not seen directly. This study aims to produce a PBL-STEM student worksheet on electronics assisted by PhET simulation on the topic of temperature and heat that is feasible and able to improve science literacy in a limited way by reviewing the results of the N-Gain score analysis.

▪ METHOD

Participants

The first semester of the 2024/2025 academic year at SMP Muhammadiyah 3 Depok, Sleman Regency, Yogyakarta, hosted this research from July 2024 to December 2024. The research subjects for the product trial developed in this study were students of class VII C with a total of 30 students.

This study divides its data collection techniques into two categories: validity data collection techniques and limited tests. The validity data collection technique was carried out by giving a product validation questionnaire sheet to 3 expert validators (material and media experts), 1 science teacher, and 2 lecturers. The aspects of product assessment that were developed include content feasibility, presentation feasibility, language feasibility, and construction validity. The assessment score is composed of four rating scale categories: invalid (score 1), less valid (score 2), quite valid (score 3), and very valid (score 4). The obtained were recapitulated and analyzed by finding the ideal mean score.

While the test technique in the limited test was carried out to measure the improvement of students' scientific literacy. The test consists of multiple choice form questions totaling 10 questions, with the assessment score of each question being 0 and 1. This test was given twice, namely before using the PBL-STEM Student Worksheet Electronics assisted by simulation PhET (pre-test) and after using the PBL-STEM Student Worksheet Electronics assisted by simulation PhET (post-test). The scores obtained were then analyzed for each item indicator to determine the N-Gain score.

Research Design and Procedures

This development research uses the 4-D model to develop products. The 4-D development model comprises four main stages: define, design, develop, and disseminate (Rasyono et al., 2020). At the define stage, researchers analyzed teachers and students on the problems faced in science subjects, especially temperature and heat material, through interviews and literature studies. This analysis includes learner analysis, task analysis, concept analysis, curriculum analysis, and formulation of learning objectives. At the design stage (planning), researchers compile test criteria, media selection, format selection, and design the initial product to be developed. At the develop stage, researchers compile products, expert assessments, and test product development. Before limited use, the product was first validated by material and media expert validators (1 teacher and 2 lecturers), and researchers made revisions according to the validator's suggestions. At the disseminate stage, the development product was implemented and tested on a limited basis on 30 students of class VII C SMP Muhammadiyah 3 Depok Sleman so that the increase in science literacy based on the N-Gain score was known.

Instruments

The instruments used to collect data include interview guidelines, validation sheets, and students' pre-test and post-test question sheets. Interview guidelines are used to obtain information on school conditions, learning conditions in the classroom, and the condition of students. The validation sheet is used to obtain data about the assessment, comments, and suggestions from expert validators on the products developed. The students' pre-test and post-test sheets each consisted of 10 questions. Each question contains science literacy indicators based on the researchers' synthesis, namely identifying scientific issues, explaining scientific phenomena, using scientific evidence, and making problem

solutions (OECD, 2019; Fives et al., 2014; Norris & Phillips, 2003; serta Norris & Phillips, 2003). Table 1 presents the preparation of the science literacy test instrument, which is based on the science literacy indicators.

Tabel 1. Indicators of science literacy

No	Indicators	Explanation	Number of Question	Question Number
1	Identifying Scientific Issues	able to identify and evaluate scientific issues in the surrounding environment regarding temperature and heat	2	1.3
2	Explaining Scientific Phenomena	able to explain natural phenomena using scientific knowledge	3	2.4.5
3	Using Scientific Evidence	able to present scientific evidence regarding temperature and heat material	2	6.10
4	Creating a problem solution	able to provide solutions to problems in accordance with the concepts of temperature and heat	3	7.8.9

Data Analysis Technique

Quantitative data obtained by researchers through validation questionnaires to expert validators were analyzed by calculating the percentage of the ideal average score and categorizing the value based on Table 2.

Table 2. Product validity categories

No	Percentage	Validity Categories
1	81% ≤ 100%	Very Valid, can be used without improvement
2	61% ≤ 80%	Moderately Valid, but needs minor improvement
3	41% ≤ 60%	Less Valid, and a major improvement
4	21% ≤ 40%	Invalid, cannot be used
5	0% ≤ 20%	Highly Invalid, cannot be used

This research conducted limited testing on 30 learners, utilizing a pre-test and post-test design, to assess the impact of the developed PBL-STEM Student Worksheet with PhET simulation on their science literacy. The data was analyzed using the N-Gain score, which aims to see the magnitude of the increase in learner literacy arising from the use of electronic PBL-STEM student worksheets assisted by PhET simulation in review with Table 3.

Table 3. N-Gain criteria

No	N-Gain Score	Category
1	0.00 < N – Gain < 0.30	Low
2	0.30 ≤ N – Gain ≤ 0.70	Medium
3	N – Gain > 0.70	High

▪ RESULT AND DISSCUSSION

Research Results Validity

Development of PBL-STEM electronic worksheets assisted by PhET simulation include define, design, develop, and disseminate stages.

Define Stage

This research conducted the define stage using two methods: interviews and literature studies. Based on the results of interviews conducted with educators and the observations of learning implementation in class VII SMP Muhammadiyah Depok Sleman, several problems in science learning were identified, including the following: Firstly, the optimal implementation of science learning remains unattainable. This is because the implementation of science learning is still carried out separately between the fields of study (Physics, Biology, and Chemistry). The lack of understanding of educators towards integrated science learning means educators have difficulty in integrating between fields of study (Physics, Biology, and Chemistry) and determining learning themes. Second, the school still uses conventional learning, which often uses the lecture method; as a result, during science learning, there are some students who are less excited (sleepy, lying on the table) when following the lesson. Third, educators still dominate science learning, leaving students unaccustomed to independently discovering concepts and facts. This results in low science literacy skills among students, as they become accustomed to receiving concepts, theories, and facts directly from educators, without gaining familiarity with the scientific process to enhance their science literacy skills. Fourth, due to space constraints at the school, practicum activities in science learning primarily consist of videos. The room, originally intended for a science laboratory, has been transformed into a computer laboratory. However, students still need to engage in science practicum activities to gain a clear understanding of the concepts, particularly in areas such as temperature and heat, which require a deeper understanding of abstract basic principles of physics that are often not directly observed. Fifth, the school has actually implemented an integrated e-Module in the Learning Management System (LMS), and the school carries the tagline “Digital School,” but in the e-Module there is no practicum activity that can be done virtually so that students lack in-depth understanding of the material. Therefore, the development of electronic student worksheets with a problem-based learning (PBL) model based on Science, Technology, Engineering, and Mathematics (STEM) supported by the PhET virtual physics laboratory is very important to create a more interactive and in-depth learning experience. This is in line with research conducted by Kamila et al. (2021) namely STEM-PBL student worksheets assisted by PhET can improve student problem-solving during the Covid-19 pandemic. Research conducted by Agustina & Dwikoranto (2021) also stated that the STEM-PBL Student Worksheet assisted by PhET can improve students' critical thinking skills. Furthermore, Putri & Ramli (2023) stated that STEM student worksheets can improve students' science literacy in middle school. In addition, PBL-STEM showed a high increase in science literacy competencies compared to the control class (Parno et al., 2020).

Design Stage

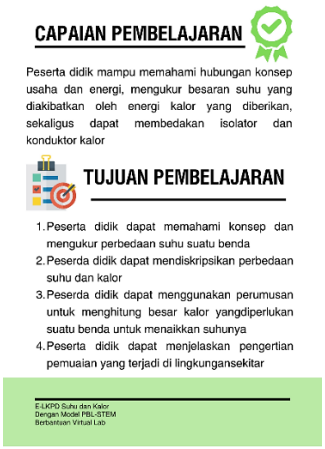
Based on the literature study conducted, after reviewing the Learning Outcomes (CP) and Learning Objectives (TP) of the Independent Curriculum Junior High School

Science, the CP and TP that will be integrated are selected. After mapping the integration of CP and TP, then selecting and determining the unifying theme, the theme of the material to be taught on the PBL-STEM Student Worksheet Electronics assisted by PhET simulation is temperature and heat. The development of PBL-STEM electronic student worksheets assisted by PhET simulation involves the design of digital worksheets that guide learners through the stages of problem solving, from problem identification to result analysis and evaluation. A virtual laboratory is used to facilitate learners to conduct temperature and heat experiments.

The development of electronic PBL-STEM student worksheets assisted by PhET simulation was developed using the steps of science process activities based on the Problem-Based Learning (PBL) learning model, namely problem orientation, organizing to learn, guiding individual and group investigations, developing and presenting results, and analyzing and evaluating the problem-solving process. This PBL-STEM Student Worksheet Electronic Product, assisted by PhET simulation, also uses an interdisciplinary educational approach, namely STEM (Science, Technology, Engineering, and Mathematics) with seventh-grade junior high school science material, namely temperature and heat. The PBL model and STEM approach are expected to improve students' literacy. The design of PBL-STEM-based E-LKPDs assisted by PhET can be seen through the link https://s.id/A0JXF and summarized in table 4.

Table 4. Design of PBL-STEM based electronic worksheets with PhET simulation

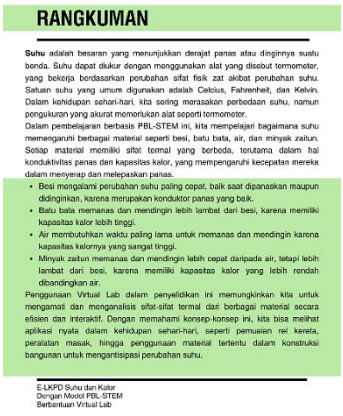
a. Front page



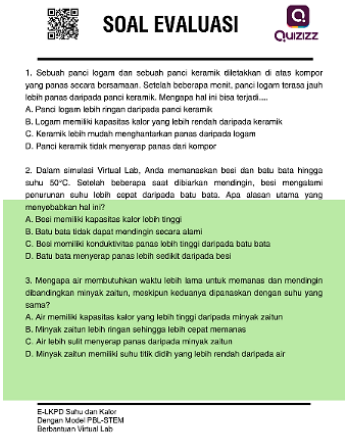
b. Learning Outcomes and Objectives

c. PBL-STEM Learning

d. Learning Activity



e. Summary Material



f. Evaluation

The media output is a website that is accessed online through Heyzine Flipbook. The preparation of science literacy test criteria in the limited test is presented in Table 1,

Develop Stage

The development of electronic PBL-STEM student worksheets assisted by PhET simulation has passed the validation stage which was assessed by three expert validators. The results of the validation of the Electronic PBL-STEM Student Worksheet assisted by PhET simulation are as follows.

Table 5. Validation result

Content Validity	Result %	Criteria
Content eligibility	94%	Very Valid
Presentation feasibility	93%	Very Valid
Language feasibility	92%	Very Valid
Construct validity	93%	Very Valid
Average	**93%**	**Very Valid**

The validity of the PBL-STEM Electronic Student Worksheet aided by PhET simulation was evaluated based on content validity and construct validity. Evaluation of content validity is divided into content suitability, presentation suitability, and language suitability. Content suitability obtained a result of 94% with a very valid category, presentation suitability obtained a result of 93% with very valid criteria, and language suitability obtained an average of 92% with very valid criteria. As for construct validity, the results obtained 93% with a very valid category. Electronic validation results of PBL-STEM Student Worksheets assisted by PhET simulation reached an overall average score of 93% with a very valid category. Overall, based on the analysis of validation results from expert validators, it is stated that the Electronic PBL-STEM Student Worksheet assisted by PhET simulation is considered very valid and feasible to use in learning junior high school science grade VII.

The validity of the developed product was then tested on a limited basis to see the effect of increasing science literacy as a result of using the development product.

Reviewing the results of research by Ummu Khairiyah et al. (2022) who developed a STEM-PBL-based PhET simulation application in the valid category proved to be able to improve students' understanding of basic science concepts. The same thing was also shown by O'Leary et al. (2020) that the PBL-STEM-based Electronic Student Worksheet categorized as valid by expert validators with an average of 86% has a positive effect compared to conventional learning. In addition to cognitive changes, students also experience increased motivation and encourage a conducive and responsive learning environment in the classroom.

Disseminate Stage

The PBL-STEM Student Worksheet Electronic Product, assisted by the PhET simulation, which was declared valid by the validator, was then tested on a limited basis at the disseminate stage with 30 students of SMP Muhammadiyah 3 Depok Sleman class VII C to determine the increase in science literacy. The increase was reviewed by comparing the N-Gain score on each indicator of science literacy through the pre-test and post-test that had been tested on students. The pre-test was given to students before being given the treatment of learning temperature and heat material with electronic PBL-STEM student worksheets assisted by PhET simulation. After the development product is implemented in learning, students are re-measured for science literacy skills with a post-test. The pre-test and post-test results were scored by reviewing each indicator and analyzing the N-Gain score for each science literacy indicator. Overall, the implementation of electronic PBL-STEM student worksheets assisted by PhET simulation provides a positive improvement to each learner. The results of the N-Gain score for each science literacy indicator are presented in Figure 1.

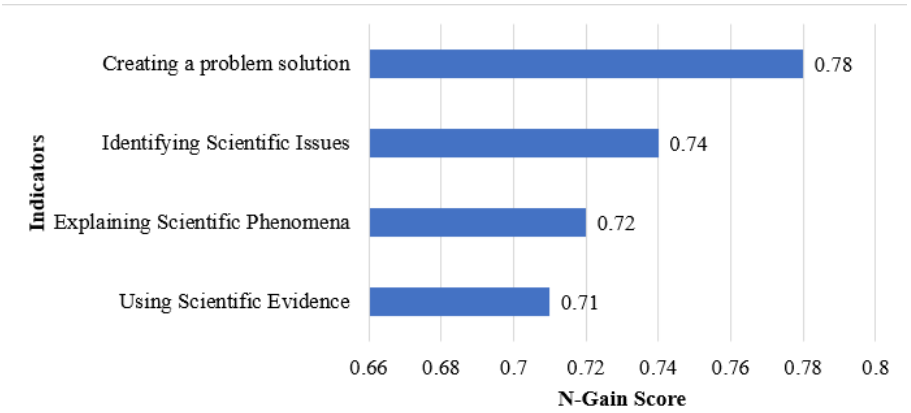


Figure 1. N-Gain score for each indicator of science literacy

Reviewing the results of the N-Gain analysis of the scores of each indicator of science literacy in the limited test, it was found that the indicators that experienced the highest to lowest increase as a result of using the development product were creating a problem solution of 0.78, identifying scientific issues of 0.74, explaining scientific phenomena of 0.72 and using scientific evidance of 0.71. Overall, the increase obtained for each indicator is categorized as high.

The use of Electronic PBL-STEM Student Worksheets assisted by PhET simulation was able to improve the ability to present problem solutions related to the concept of

temperature and heat in the indicator of creating a problem solution. This indicator obtained a higher N-Gain score compared to other indicators. The application of the PBL learning model in the development product requires students to get used to presenting problem solutions in real life based on scientific concepts (Ittycheria et al., 2024; Jonassen, 2011). The use of the PBL learning model is also able to train reasoning and solve real problems critically (Bae et al., 2021). The STEM approach in a PBL environment not only improves cognitive skills but also makes learners better prepared to solve complex problems scientifically (Fitriyani et al., 2023). In line with research conducted by Safitri et al., (2021) at Jambi University, namely developing PBL-STEM-based electronic student worksheets, which succeeded in improving students' understanding and science literacy skills on reaction rate material.

The indicator of identifying scientific issues ranks second among the four indicators of increased science literacy, as measured by the increase in the N-Gain score. The integration of PhET virtual labs in development products facilitates the identification of scientific issues by enabling students to observe, identify, and evaluate a physical condition (Yaipen, 2023). The integration of virtual labs into development products fosters interaction with students, encouraging them to engage in learning and develop an enthusiasm for observing and identifying abstract concepts in temperature and heat theory (Haryadi & Pujiastuti, 2020).

The electronic PBL-STEM student worksheet, assisted by a PhET simulation, that has been tested in a limited trial has been proven to be able to provide an increase in science literacy for students. To access all features of this development product without lengthy loading times, a stable internet connection is necessary. Students can briefly access this development product by integrating its distribution process into the school's Learning Management System (LMS). To implement all features in learning and maximize improvements in science literacy, educators must have a thorough understanding of operating development products and designing integrated learning schemes with them.

Future research can test this development product's effectiveness by pairing it with other teaching materials. This will aid in preparing future educators to tackle the challenges posed by an increasingly fast-paced world. We must acknowledge the crucial role of learning media in executing the learning process. Interesting learning media can encourage students to absorb the presented material (Setyo et al., 2023). So, the features and materials in the development product can be developed again on the topic of other junior high school science materials so that interactive and quality teaching resources can be a provision for teachers in teaching and learning activities.

▪ CONCLUSION

The discussion and results show that the PBL-STEM Electronic Student Worksheet with PhET simulation on temperature and heat is valid, as shown by the average score of 93% on the validity analysis. It can also improve students' science literacy, as shown by the high N-Gain category in each science literacy indicator in limited testing at SMP Muhammadiyah 3 Depok Sleman. The most improved indicator is the ability to create a problem solution, which is a tangible manifestation of the integration of PBL in the developed electronic worksheets. The PhET virtual lab, which provides support, enhances

the indicator of identifying scientific issues by enabling students to visually observe and evaluate the physical processes associated with temperature and heat.

This research provides solutions and references to junior high school science learning media that can have a cognitive impact on improving science literacy and the impact of an interactive, active, and critical teaching and learning environment with the implementation of the developed products. Broad implementation by comparing treatments in each class has not been carried out in this study. Time constraints and the duration of the educational curriculum are limiting factors in this development study. For further studies, a comparative study can be conducted regarding the comparison of the effectiveness of the use of PBL-STEM Student Worksheet Electronic products assisted by PhET simulation with other teaching materials and able to cover cognitive and affective abilities in junior high school science learning.

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