



The Effectiveness of STEM Inquiry-Based E-Book on Temperature and Heat to Improve Senior High School Students' Scientific Literacy

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ABSTRACT

Education in Indonesia faces low student abilities in scientific literacy. Scientific literacy is essential for students to understand, evaluate, and use knowledge so they can use scientific concepts in learning and daily life. This study aims to determine the effectiveness of STEM inquiry-based e-books on temperature and heat in improving high school students' scientific literacy skills. This study uses a quasi-experimental research design and cluster random sampling technique. Data analysis used statistical tests using the SPSS application. Prerequisite tests were carried out in stages, namely normality tests and homogeneity tests. Effectiveness tests include the N-gain test, Manova test, and Effect Size. The results of this study indicate that the use of STEM inquiry-based e-books on temperature and heat is better in improving students' scientific literacy skills. The effectiveness of STEM inquiry-based e-books on temperature and heat is obtained based on the difference in average pretest-posttest scores and the increase in pretest-posttest scores in each class. The experimental class that used STEM inquiry-based e-book learning products on temperature and heat material experienced higher improvement compared to the control class 1 that used regular e-books without inquiry models and the control class 2 that used printed school books.

Keyword: Effectiveness, STEM Inquiry-Based E-book, Temperature and Heat, Scientific Literacy

INTRODUCTION

In this century's learning, students need skills that align with current developments in the learning process, one of which is scientific literacy. Skills in scientific literacy are anticipated to enable students to recognize issues and tackle them, as well as to discover possible solutions (Adriyawati et al., 2020). Learners who possess scientific literacy will apply scientific principles and inquiry skills to evaluate and make decisions in their daily interactions with people, society, and the environment (Rahmawati et al., 2024).

Indonesian education faces a lack of scientific literacy skills among students. The PISA scientific literacy assessment supports the international concern about low. PISA is an international survey conducted for students starting at age 15 by measuring learning outcomes essential for success in the 21st century. Based on data from the OECD PISA assessment on Indonesian students' scientific literacy, Indonesia has experienced a decline, with a score of 396. Indonesia ranked 70th out of 78 countries in 2018 (OECD, 2019). According to PISA 2022

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statistics, Indonesian students' average scientific literacy skills declined from 2018 to 2022 (OECD, 2023). This demonstrates that students' scientific literacy needs greater attention for future progress.

Low scientific literacy is evidenced by previous studies. According to research by Juwita Sari & Rosdiana (2024), students at a Serang City high school still have inadequate levels of scientific literacy, and their attitudes toward literacy tend to be indifferent and lazy. Research by Intan Rahmawati et al. (2024) on the scientific literacy skills of students at a high school in Lampung found an average of 40% in the "very poor" category across three aspects of scientific literacy. According to studies by Azura et al. (2021), students' scientific literacy in physics is generally low, with average percentages of 46%, 63%, and 61%. This implies that students' scientific literacy is still deficient when it comes to elucidating scientific elements in a variety of intricate.

This research suggests that low scientific literacy is also a problem in education in several other countries. Research by Noor (2021) shows that the scientific literacy level of students in rural Malaysian schools is lower than that of students in the UK, based on three competency aspects established by the OECD. A study was also conducted by Ceylan & Seven (2023) in Turkey, it was shown that the scientific literacy level among secondary school students remains relatively low. Research by Pentin et al. (2018) shows that scientific literacy among Russian students tends to be low, especially compared to international standards as measured by PISA. Overall, scientific literacy needs to be improved, especially in terms of applying scientific knowledge and skills in real-world contexts.

Several factors that may contribute to low scientific literacy include students' low positive attitudes toward understanding science and the lack of interest in several basic competencies related to content, process, and context in learning (Hatta et al., 2021). Students are not yet accustomed to questions presented in discourse form, and the learning process does not support student literacy (Badaruddin et al., 2024). And the use of student textbooks or teaching resources in learning is still limited to textbooks or texts that do not support scientific literacy (Suparya et al., 2022).

Learning media that support the learning process must be more engaging, creative, and practical to capture students' attention (Aswirna et al., 2020). Students' curiosity is piqued by the use of technology in educational materials, which makes learning more interesting and pleasurable (Munawaroh et al., 2023). Effective learning media can support the improvement of students' scientific literacy skills.

Among various forms of technology-based learning media, e-books are widely used in education due to their flexibility and interactive features. E-books are books in digital format that can be accessed through various electronic devices. E-books can develop reading and text comprehension skills, which are crucial for improving scientific literacy and can support contextual learning by presenting information that is relevant and applicable to everyday life (Savva et al., 2021). The advantages of e-books include easy access anywhere and anytime using electronic devices, and engaging learning materials in the form of text, animations, images, and videos (Nadhifah, 2022). E-books have significant potential to enhance students' learning experiences by encouraging collaboration and discussion to build understanding of learning concepts and communicate their findings (Yau et al., 2023).

Aside from the use of learning media, the learning model plays a crucial role in shaping learning activities to ensure they align with the intended educational goals. The learning model must actively engage students in learning and provide opportunities for them to develop

scientific literacy skills. The inquiry learning model encourages students to engage more actively in the educational process (Kırcı & Bakırcı, 2021). The inquiry learning model helps students develop their scientific skills, including formulating questions, designing experiments, and analyzing essential data (Yenice & Özden, 2022).

The inquiry learning model is highly suitable for integration with the STEM approach. STEM is a learning approach that utilizes concepts from science, technology, engineering, and mathematics (Shukshina et al., 2021). The goal of the STEM approach is to encourage students to research, identify, explore, and ask questions, thus equipping them with problem-solving, creative, critical, innovative, decision-making, communication, and collaborative thinking skills (Kırcı & Bakırcı, 2021). Research by Arsad et al. (2023), the STEM approach improves scientific literacy skills, particularly in aspects of scientific knowledge and the application of science in everyday life. STEM learning not only develops 21st-century skills in general but also contributes specifically to the development of scientific literacy. The STEM approach encourages collaboration, the exchange of ideas, and effective communication with peers to solve problems, which are all aspects of scientific literacy.

Temperature and heat are fundamental concepts in physics with broad applications in everyday life, such as heating, cooling, and phase changes of matter. Research has found that many students have significant misconceptions regarding the concepts of temperature and heat (Sukarelawan, Moh. Irma, 2024). For example, students often assume that temperature depends on an object's size or mass, or that two different temperatures can be added together, or how heat transfers between objects. The topic of temperature and heat requires scientific literacy because these concepts are closely related to everyday phenomena, such as weather changes, the use of thermometers, heat transfer in cooking utensils, and the process of maintaining body temperature. When students have misconceptions about temperature, heat, and heat transfer, they will have difficulty connecting these concepts to real-world situations and solving problems scientifically.

The integration of e-books using a STEM approach with an inquiry model on temperature and heat is novel, as research combining the three is still limited. This research is highly relevant considering the learning in this era. This research is very helpful in creating more creative and engaging learning media according to current learning needs. This study aims to assess how well STEM inquiry-based physics e-books enhance scientific literacy regarding heat and temperature.

METHOD

Research Design

The sampling method employed in the quasi-experimental research design was cluster random sampling. This study was carried out in three classes, as two control classes and one experimental class at a state senior high school in West Sumatra, Indonesia. In the preliminary phase, researchers conducted classroom and school observations. After identifying problems, they sought to identify the factors contributing to the problems. The results of the pretest and initial observations served as a guide in developing the learning materials. This lesson consisted of teaching modules, student worksheets (LKPD), e-book learning media, test instruments, assessment rubrics, and observation sheets.

The study's independent variable was the educational materials utilised in each lesson. The experimental class used a STEM inquiry-based e-book, control class 1 used a regular e-

book without an inquiry model, and control class 2 used a printed textbook commonly used in schools. Students' scientific literacy abilities served as the study's dependent variable. Meanwhile, the control variables included the teaching teacher, learning duration, and pretest and posttest instruments that were the same across all classes to maintain consistency in learning conditions. In addition, a product practicality questionnaire was given specifically to the experimental class to evaluate the practicality of the STEM-based e-books with an inquiry model. Scientific literacy skills were measured using a reasoned multiple-choice test through a pretest and posttest based on the indicators used. Table 1 displays the pretest-posttest design for the control group.

Table 1. Design Control Group Pretest-Posttest

Group	Pretest	Treatment	Posttest
Eksperiment	P ₁	X	P ₂
Control 1	P ₁	C ₁	P ₂
Control 2	P ₁	C ₂	P ₂

Description:

P1: Pretest questions for scientific literacy skills

P2: Posttest questions for scientific literacy skills

X: Experimental class treatment (learning using a STEM inquiry-based e-book on temperature and heat)

C₁: Control class treatment 2 (regular e-book media without an inquiry model)

C₂: Control class treatment 3 (school-printed textbook media)

Participants

Eleventh-grade students in the even semester of a West Sumatra state senior high school during the 2024–2025 school year are the subjects of the study. A cluster random sample was the sample method employed in this investigation. The researcher will choose three classes that will be treated equally as research subjects using this sampling technique. With thirty students, Class XI F.1 was the experimental class, with thirty-four students, Class XI F.2 was the first control class, and with thirty-three students, Class XI F.3 was the second control class.

Instruments

The test instrument was validated by two physics lecturers before use. After the validation and revision process, a valid and reliable instrument was produced for measuring students' scientific literacy. The test was administered twice: a pretest administered before using the STEM inquiry-based e-book, and a posttest administered after using it. The twenty multiple-choice questions in the scientific literacy test were split between ten pre-test and ten post-test items. Both sets of questions were developed based on the same scientific literacy indicators for temperature and heat. The scientific literacy test item outline is presented in Table 2.

Table 2. Science Literacy Question Grid

Scientific Literacy Indicator	Item Indicator	Item Number
Scientific Knowledge	Determining the concept of heat transfer in the phenomenon of clothes drying during the day	2
	Relating theoretical concepts and providing explanations based on scientific phenomena	10
	Analyzing heat transfer data through conduction, convection, and radiation	16
Thinking and Working Scientifically	Identifying phenomena of changes in the states of liquid and gas	3
	Analyzing the phenomenon of differences between temperature and heat in the human body	6
	Calculating the amount of heat required based on the given data	7
	Understanding the phenomenon of heat transfer in crocodiles and selecting explanations appropriate to the concept	8
Science, Technology, and Society	Calculating the mixed water temperature using the concept of thermal equilibrium and the principle of energy conservation	20
	Determining examples of heat transfer in everyday life	11
Explaining Phenomena Scientifically	Determining the concept of heat transfer in lakes	1
	Calculating temperature based on the given data	18
	Calculating the amount of heat required based on the given data	19
Evaluating and Designing Scientific Investigation	Explaining the reason for choosing an alcohol thermometer over a mercury thermometer	12
	Analyzing or interpreting experimental conclusions based on data or experiments	13
	Applying the concept of radiation in the use of infrared heaters	15
	Calculating the temperature of an object in a particular unit	9
	Relating knowledge to real-life situations and analyzing the reason for thermal expansion in railway tracks	17
Interpreting Scientific Data and Evidence	Calculating the mixed temperature during thermal equilibrium in water	4
	Analyzing the concept of a mercury thermometer	5
	Understanding the relationship between heat and changes in the states of matter	14

Data Analysis

Data analysis in this study was performed using statistical tests using SPSS. The statistical testing process consisted of prerequisite tests and effectiveness tests. The prerequisite tests were conducted in stages, namely, normality tests and homogeneity tests. The effectiveness tests included the N-gain test, MANOVA test, and Effect Size test.

RESULTS AND DISCUSSION

Results

This study was conducted by administering a pretest before the lesson to determine students' initial abilities in the temperature and heat topics. After the lesson, a posttest was administered to determine whether there had been any improvement in students' abilities in the temperature and heat topics. The average scores for each class are shown in Figure 1.

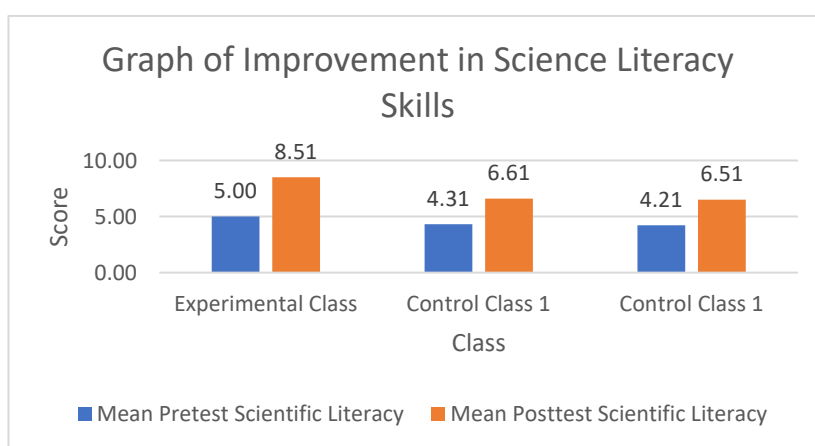


Figure 1. Average Pretest and Posttest Score

The graph indicates that students in the experimental class improved more than those in the control group in terms of scientific literacy. The experimental class's pretest average of 5.00 increased to 8.51 in the posttest, a difference of 3.51 points. Conversely, control class 1 increased from 4.31 to 6.61 (a difference of 2.30 points), and control class 2 from 4.21 to 6.51 (a difference of 2.30 points). The greater improvement in the experimental class indicates that the STEM inquiry-based e-book on temperature and heat was more successful than the instruction utilised in the control class at raising students' scientific literacy.

The prerequisite tests used were normality and homogeneity tests. The Shapiro-Wilk test was used to assess normality in Table 3. The data were regularly distributed if the significance value was higher than 0.05. The homogeneity test was conducted to test for equality of variance, which aimed to compare the abilities of the classes using Levene's Test. The homogeneity test can be seen in Table 4.

Table 3. Normality Test Results

	Class	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	Df	Sig.	Statistic	df	Sig.
Pretest_Scientific_Literacy	XI F.1	.133	30	.183	.963	30	.368
	XI F.2	.135	34	.117	.941	34	.067
	XI F.3	.120	33	.200*	.968	33	.422
Posttest_Scientific_Literacy	XI F.1	.175	30	.019	.931	30	.053
	XI F.2	.146	34	.063	.944	34	.082
	XI F.3	.102	33	.200*	.974	33	.597

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 4. Results of Homogeneity Test

		Levene Statistic	df1	df2	Sig.
Pretest_Scientific_Literacy	Based on Mean	.421	2	94	.658
	Based on Median	.423	2	94	.656
	Based on Median and with adjusted df	.423	2	89.005	.656
	Based on trimmed mean	.437	2	94	.647
Posttest_Scientific_Literacy	Based on Mean	.234	2	94	.792
	Based on Median	.257	2	94	.774
	Based on Median and with adjusted df	.257	2	90.656	.774
	Based on trimmed mean	.242	2	94	.786

After conducting normality and homogeneity tests, the n-gain test, MANOVA test, and Effect Size test were then conducted. Improvement in scientific literacy skills can be determined through the n-gain scores in each class. The results of the n-gain scores for students' scientific literacy skills on temperature and heat are shown in Table 5.

Table 5. N-Gain Analysis of Scientific Literacy Skills

Class	Pretest	Posttest	N-gain	Category
Experimental Class	5.00	8.51	0.71	High
Control Class 1	4.31	6.61	0.39	Medium
Control Class 2	4.21	6.51	0.39	Medium

According to the table, the experimental class's n-gain score was 0.71, falling into the high range. Meanwhile, the n-gain score in control classes 1 and 2 was 0.39, which is in the medium category. The highest score increase was in the experimental class, which used a STEM inquiry-based e-book on temperature and heat in its learning activities.

The MANOVA test was based on the results of the multivariate test and post hoc test. The results of the multivariate test were used to simultaneously determine the significance of differences in students' scientific literacy skills across the three study classes. The results of the multivariate test are presented in Table 6. The results of the post hoc test were used to

determine the specific location of differences between classes.

Table 6. Multivariate Test Results

	Effect	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power^c
Time	Pillai's Trace	.915	1008.014 ^b	1.000	94.000	.000	.915	1008.014	1.000
	Wilks' Lambda	.085	1008.014 ^b	1.000	94.000	.000	.915	1008.014	1.000
	Hotelling's Trace	10.724	1008.014 ^b	1.000	94.000	.000	.915	1008.014	1.000
	Roy's Largest Root	10.724	1008.014 ^b	1.000	94.000	.000	.915	1008.014	1.000
Time Class	*Pillai's Trace	.315	21.652 ^b	2.000	94.000	.000	.315	43.303	1.000
	Wilks' Lambda	.685	21.652 ^b	2.000	94.000	.000	.315	43.303	1.000
	Hotelling's Trace	.461	21.652 ^b	2.000	94.000	.000	.315	43.303	1.000
	Roy's Largest Root	.461	21.652 ^b	2.000	94.000	.000	.315	43.303	1.000

a. Design: Intercept + Class
 Within Subjects Design: time
 b. Exact statistic
 c. Computed using alpha = .05

The MANOVA test results indicate a significance level of 0.00, which is less than 0.05, according to Table 6. The significance value obtained indicates that there are simultaneous differences in students' scientific literacy abilities across the three research classes. This means that H1 is accepted and H0 is rejected, indicating a significant influence of all three classes on the scientific literacy variable simultaneously. This analysis stage indicates significant differences across the three classes. Based on this, a further post hoc test is necessary to determine the specific differences between the classes.

Table 7. Post Hoc Test Results (Multiple Comparisons)

(I) Class	(J) Class	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
XI F.1	XI F.2	1.2946*	.16263	.000	.8982	1.6910
	XI F.3	1.3943*	.16378	.000	.9951	1.7936
XI F.2	XI F.1	-1.2946*	.16263	.000	-1.6910	-.8982
	XI F.3	.0997	.15866	1.000	-.2870	.4864
XI F.3	XI F.1	-1.3943*	.16378	.000	-1.7936	-.9951
	XI F.2	-.0997	.15866	1.000	-.4864	.2870

Based on observed means.
 The error term is Mean Square(Error) = .422.
 *. The mean difference is significant at the .05 level.

Based on the post hoc test results (multiple comparisons) with Bonferroni correction, information was obtained on the average differences between classes. The magnitude of the mean difference (MD) value indicates the level of achievement differences between classes.

There was a significant difference between class XI F.1 and class XI F.2 ($MD = 3.956$; $p = 0.000 < 0.05$) and between class XI F.1 and class XI F.3 ($MD = 4.736$; $p = 0.000 < 0.05$). This indicates that the average learning outcomes of class XI F.1 students were significantly higher than those of the other two classes.

Conversely, the comparison between class XI F.2 and class XI F.3 did not show a significant difference ($MD = 0.780$; $p = 0.716 > 0.05$). This indicates that the learning outcomes of class XI F.2 and class XI F.3 students were relatively similar, while class XI F.1 had significantly superior achievement. The table shows that the learning treatment applied to class XI F.1 had a greater impact on student learning outcomes than the control class. Following the MANOVA test, an effect size test was conducted.

Effect size was used to treatment's influence or the effectiveness of the STEM inquiry-based e-book on temperature and heat on students' scientific literacy skills. The effect size value was calculated using Cohen's f value, which is derived from the partial eta-squared value. The results of the effect size analysis can be seen in Table 8.

Table 8. Effect Size Test Results

Partial Eta Squared	Sig	Cohen's f	Kriteria
0,915	0,000	3,28	Besar

Based on the results of the effect size test using Cohen's f , the Time factor had an f value of 3.28 with a partial eta squared of 0.915. This value far exceeds Cohen's criteria for large differences, thus concluding that scores across time have a very strong influence. This indicates a statistically significant treatment effect across classes over time. Therefore, it can be concluded that the STEM inquiry-based e-book on temperature and heat has an effective impact.

Discussion

The effectiveness of the STEM inquiry-based e-book on temperature and heat was determined based on pretest-posttest scores. This efficacy was demonstrated by the increase in pretest-posttest scores and the difference in average pretest-posttest scores. The difference between the scientific literacy abilities scores is calculated using the multivariate test data in Table 6. According to these results, H_1 is approved, and H_0 is denied because the p -value is less than 0.05. This shows that the experimental class, control class I, and control class II had different pretest-posttest results. This discrepancy shows how the pretest and posttest results for each of the three courses differed significantly.

Table 7 shows the results of the post hoc test with Bonferroni correction. Significant differences were found between class XI F.1 and class XI F.2, and between class XI F.1 and class XI F.3. These results indicate that the average learning outcomes of class XI F.1 students were significantly higher than those of the other two classes. Conversely, the comparison between class XI F.2 and class XI F.3 did not show a significant difference. This indicates that the learning outcomes of class XI F.2 and class XI F.3 students were relatively similar, while class XI F.1 achieved significantly higher results. Therefore, overall, the learning treatment applied to class XI F.1 had a better impact on improving students' scientific literacy compared to the control classes (XI F.2 and XI F.3). Based on the significance value and MD value, it can be concluded

that the order of achievement from highest to lowest is class XI F.1 > class XI F.2 > class XI F.3.

The results of this study indicate that the experimental class using a STEM inquiry-based e-book on temperature and heat experienced a greater increase in scientific literacy skills. The STEM inquiry-based e-book was designed by integrating the stages of the inquiry model with STEM components on temperature and heat. The stages of inquiry include orientation, problem formulation, hypothesis formation, data collection, hypothesis testing, and conclusion drawing. These stages are integrated with STEM elements through the presentation of contextual phenomena, the use of technology-based learning activities, problem-solving related to engineering, and mathematical analysis. In addition, the e-book also contains scientific literacy-oriented questions arranged based on scientific literacy indicators, as shown in Table 2. This integration has the potential to improve students' scientific literacy skills. Therefore, the STEM inquiry-based e-book on temperature and heat effectively improves students' scientific literacy skills compared to conventional e-books without an inquiry model and printed school textbooks.

These findings align with research by Kaynar et al. (2020), who found that the use of e-books can improve literacy by providing better access to information, increasing student engagement, and fostering the skills necessary to understand and use scientific information effectively. Research by Sulisetijono et al. (2023) found that the use of e-books in education can significantly contribute to improving students' scientific literacy innovatively and engagingly, helping students become more skilled at understanding and applying scientific knowledge in everyday life. STEM-based education has been identified as a pedagogical approach with the potential to prepare students to develop scientific literacy and problem-solving skills (Irwanto et al., 2022). Research by Rahmi et al. (2025) stated that STEM-based teaching materials can improve 21st-century skills, including scientific literacy. Furthermore, teaching materials need to be adapted to learning models and learning needs, as well as integrated with current technological developments. Therefore, STEM inquiry-based e-books on temperature and heat are more effective in improving scientific literacy skills compared to regular e-books without inquiry models and school textbooks.

Research conducted by Natale et al. (2021) found that inquiry learning encourages students to engage directly in scientific processes, such as formulating questions, designing experiments, collecting data, and analyzing results. This engagement helps students develop essential skills in scientific literacy, such as the ability to conduct research, understand, and evaluate scientific information. Research by Ormancı & Çepni (2020) found that the inquiry learning model encourages students to actively engage in the learning process through activities such as investigations, participating in discussions, collaboration, and presentations.

Previous research has generally focused on only one aspect, such as e-books, STEM approaches, or inquiry learning models, separately. Therefore, this study complements these aspects by integrating STEM components and stages of inquiry learning models into an interactive e-book on temperature and heat. The e-book is designed to incorporate inquiry stages and STEM elements by presenting contextual phenomena in everyday life, problem-solving activities, data analysis, and scientific literacy-oriented questions. The advantages of this STEM-based inquiry e-book lie in its interactive and flexible format, as well as the inclusion of scientific literacy-oriented assignments that encourage active student engagement throughout the learning process. However, this e-book also has limitations, such as requiring a stable internet connection and adequate smartphone or computer facilities for optimal access and use. Future research is expected to develop e-books with more varied learning models and

approaches for other learning materials.

CONCLUSION

The results of this study concluded that the use of STEM inquiry-based e-books on temperature and heat was more effective in improving students' scientific literacy skills. The effectiveness of the STEM inquiry-based e-books on temperature and heat was determined based on the difference in average pretest-posttest scores and the increase in pretest-posttest scores in each class. The experimental class using the STEM inquiry-based e-book on temperature and heat experienced greater improvement compared to control class 1, which used a regular e-book without an inquiry model, and control class 2, which used a printed school textbook. Therefore, the STEM inquiry-based e-book on temperature and heat developed was effective in improving students' scientific literacy skills, surpassing the gains achieved through regular e-books without an inquiry model and printed school textbooks.

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