Development of STEM-Based Physics E-Book to Improve Creative Thinking Abilities of Grade XI High School Students

Riski Safitri[a)], Jumadi[b)]

[1] *Department of Physics Education, Sekolah Tinggi Keguruan dan Ilmu Pendidikan Tanjungpura, Jl. KH. Mansyur, Kelurahan Tengah, Kec Delta Pawang, Kab. Ketapang Kalimanatan Barat 78811, Indonesia*
[2] *Department of Physics Education, Universitas Negeri Yogyakarta, Jl. Colombo No.1, Karang Malang, Caturtunggal, Yogyakarta 55281, Indonesia*

Email: [a)]safitrisky827@gmail.com, [b)]jumadi@uny.ac.id

Abstract

This study aimed to develop a STEM-based physics e-book on the topic of temperature and heat and to examine its validity, practicality, and potential to improve senior high school students' creative thinking abilities. This research employed a Research and Development (R&D) approach using the 4-D development model (Define, Design, Develop, and Disseminate) combined with a quasi-experimental pretest–posttest design. The study involved 262 students for empirical instrument testing, 30 students for the limited product trial, and 91 students for the field trial conducted at three public senior high schools in Baubau, Indonesia. Data were collected using expert validation sheets, student and teacher response questionnaires, and an 18-item reasoned multiple-choice test of creative thinking abilities. Content validity was analyzed using Aiken's V, empirical item quality and reliability were evaluated using the QUEST program, and the effectiveness of the developed e-book was analyzed using the Generalized Linear Model (GLM). The results indicated that the developed STEM-based physics e-book achieved very good validity in both material and media aspects and demonstrated very good practicality based on teacher and student evaluations. Students who learned using the STEM-based physics e-book obtained higher posttest scores and the largest practical effect size (partial eta squared = 0.614) compared with the comparison groups. However, the Bonferroni post hoc analysis indicated that the differences between groups were not statistically significant in all pairwise comparisons. These findings suggest that the developed STEM-based physics e-book has the potential to support the development of students' creative thinking abilities and can serve as an alternative digital learning resource for teaching temperature and heat.

Keywords: creative thinking abilitities, physics e-book, STEM, temperatur and heat.

INTRODUCTION

Education plays a crucial role in developing students' competencies to enable them to face the challenges of the 21st century. In addition to mastering knowledge, the learning process is also expected to foster higher-order thinking skills, including creative thinking (Gunawan et al., 2018). This ability is essential for students to generate diverse ideas, analyze problems from multiple perspectives, and find innovative solutions to challenges (Zainudin & Istiyono, 2019). Therefore, developing creative thinking abilities is a crucial goal in physics learning.

In physics learning, creative thinking abilities not only help students understand scientific concepts but also support them in solving problems related to everyday life phenomena. Students are required to connect the concepts learned with real situations through the process of

observing, analyzing, designing solutions, and evaluating the results of problem solving (Nurita et al., 2017). However, various studies show that students' creative thinking abilities are still relatively low. This condition is indicated by students' low ability to put forward ideas, develop various alternative solutions to problems, and produce original ideas (Athifah & Syafriani, 2019; Utami et al., 2019). These low abilities are influenced by various factors, such as the learning process that is still teacher-centered, the lack of opportunities for students to explore ideas, and the use of teaching materials that are not able to encourage creative thinking activities.

One of the physics topics chosen for this study is temperature and heat because they are fundamental concepts that serve as the foundation for studying various other physics topics, such as changes in state of matter, the kinetic theory of gases, and thermodynamics (Yeo & Zadnik, 2001; Hsieh et al., 2014). In addition to their crucial role in physics learning, the concepts of temperature and heat are closely related to various phenomena encountered in everyday life, so students are expected to be able to relate these concepts to real-world situations (Turgut & Gurbuz, 2012). However, temperature and heat remain a topic that often causes difficulties for students because they contain abstract concepts and require the ability to connect concepts to various contextual phenomena.

Various studies have shown that students still experience misconceptions, such as considering temperature and heat to be the same concept, difficulty explaining the mechanisms of heat transfer, and inability to apply the relationship between heat, temperature changes, and changes in state of matter to solve contextual problems (Astari et al, 2022; Fauziah & Anansa, 2023). These conditions indicate that learning about temperature and heat requires strategies and teaching materials that not only help students understand the concepts but also facilitate their exploration of ideas, discussions, and development of creative thinking skills through problem-solving activities (Turgut & Gurbuz, 2012; Chu et al., 2012).

The characteristics of temperature and heat materials provide significant opportunities for integration with the Science, Technology, Engineering, and Mathematics (STEM) approach (Kelley & Knowles, 2016). Various phenomena, such as the use of insulators and conductors, thermos design, the efficiency of thermal energy use in buildings, and the application of heat-utilizing technology, can be used as authentic learning problems (Margot & Kettler, 2019). By solving these problems, students are encouraged to integrate concepts from science, technology, engineering, and mathematics to generate creative solutions. Thus, the STEM approach not only helps students understand the concepts of temperature and heat more meaningfully but also provides learning experiences that foster creative thinking abilities (Fiteriani et al., 2021; Ilafi et al., 2024).

One alternative that can be used to address this problem is the use of STEM-based e-books. The integration of Science, Technology, Engineering, and Mathematics (STEM) in e-books allows students to learn through contextual problems, conduct investigations, design solutions, and connect physics concepts with their real-life applications (Thibaut et al., 2018; Parmin & Sajidan, 2019). Compared to conventional e-books, which generally only present material in digital format, STEM-based e-books provide a more interactive learning experience through problem-solving activities, simple experiments, student worksheets, and evaluations designed to develop creative thinking abilities (Sukmagati et al., 2020; Sayyadi et al., 2016).

Although extensive research on e-books and STEM-based learning has been conducted, most research focuses on the development of digital teaching materials or the application of STEM approaches separately (Kelley & Knowles, 2016; Margot & Kettler, 2019). Research specifically developing STEM-based physics e-books on temperature and heat to enhance students' creative thinking abilities is still relatively limited. Therefore, this study seeks to fill

this gap by developing STEM-based physics e-books designed to address the characteristics of temperature and heat materials and the needs of 21st-century learning. Based on this background, this study aims to: (1) produce a STEM-based physics e-book on the topic of temperature and heat that meets valid and practical criteria, (2) analyze the effectiveness of the developed e-book in improving students' creative thinking abilities, and (3) describe the improvement in students' creative thinking abilities after using a STEM-based physics e-book in the learning process.

METHODS

This study employed a Research and Development (R&D) approach using a 4-D development model consisting of four stages: defining, designing, developing, and disseminating. In the defining stage, classroom observations and interviews with physics teachers were conducted to identify students' learning difficulties, particularly on the topic of temperature and heat, and to determine the need for developing STEM-based learning materials. The designing stage involved preparing the e-book structure, designing learning activities, developing student worksheets (LKPD), preparing assessment instruments, and integrating STEM components into each learning activity. In the developing stage, the prototype was evaluated through expert validation, empirical testing of the instrument, limited-scale trials, and field implementation to determine the validity, practicality, and effectiveness of the developed e-book. Finally, the dissemination stage was carried out by introducing the validated e-book to physics teachers and schools as an alternative digital learning resource.

The learning activities embedded in the e-book are developed by integrating four STEM components with Problem-Based Learning (PBL) syntax. The science component is implemented through conceptual exploration of temperature and heat phenomena. Technology is represented by the use of digital simulations, multimedia, and interactive learning resources contained in the e-book. Engineering is integrated through problem-solving and design activities that require students to propose solutions to real-world problems related to temperature and heat, while mathematics is applied in data analysis, calculations, graph interpretation, and quantitative reasoning. These STEM components are implemented following the PBL stages, namely problem orientation, problem identification, investigation, solution development and presentation, and evaluation of the problem-solving process.

The effectiveness of the developed e-book was examined using a quasi-experimental design with pre-test and post-test control groups. Cluster sampling was used because the existing classes could not be randomly reorganized. Three intact eleventh-grade science classes at SMAN 3 Baubau were selected from classes with relatively similar academic characteristics based on school records and consultation with the physics teacher. Prior to the treatment, the equivalence of the three classes was checked using pretest results. The selected classes consisted of one experimental class learning using a STEM-based physics e-book, one control class using a physics e-book without STEM integration, and one control class learning using a printed physics textbook. To avoid inconsistencies, the learning media used in each group were maintained throughout the study.

The study subjects consisted of 262 eleventh-grade students from SMAN 1 Baubau, SMAN 3 Baubau, and SMAN 4 Baubau who participated in the empirical testing of the instrument. A limited pilot test involving 30 students was conducted to evaluate the readability and practicality of the e-book before implementation in the classroom. The field trial involved a total of 91 students from SMAN 3 Baubau, consisting of 31 students in the experimental class, 30 students in Control Class I, and 30 students in Control Class II.

Data were collected through classroom observations, interviews with physics teachers, expert validation sheets, student and practitioner response questionnaires, documentation, and a creative thinking abilities test. The creative thinking test consisted of 18 reasoned multiple-choice items designed to measure four indicators of creative thinking: fluency, flexibility, originality, and elaboration. Each item required students to select the correct answer and provide logical reasoning, with scoring based on a predetermined rubric that included answer accuracy and reasoning quality. The instrument's content validity was evaluated using Aiken's V, while empirical validity, item suitability, and reliability were analyzed using the QUEST program before the instrument was administered in the field trial.

The collected data were analyzed using descriptive and inferential statistics. The expert validation, practicality questionnaire, and response questionnaire were analyzed descriptively, while the effectiveness of the developed e-book was examined using a Mixed Design ANOVA based on a General Linear Model (GLM). Prior to the analysis, the assumptions of normality, homogeneity of variance, and sphericity were checked. When the sphericity assumption was violated, the Greenhouse-Geisser correction was applied to obtain more accurate significance values. All statistical analyses were conducted to compare changes in students' creative thinking abilities before and after the implementation of the STEM-based physics e-book.

RESULTS AND DISCUSSION

Result

The STEM-based physics e-book was developed using the 4-D development model, which consists of four sequential stages: define, design, develop, and disseminate. Each stage produced specific outcomes that contributed to the development and evaluation of the e-book. The results obtained at each stage are presented as follows.

Define

Initial Product Development

Preliminary Study

The preliminary study was conducted through classroom observations, interviews with physics teachers, and a review of existing learning conditions. The findings indicated that students' creative thinking abilities were still relatively low, even though these skills are essential for learning physics in the twenty-first century. Most students experienced difficulties when solving physics problems because they were not accustomed to following a systematic problem-solving process or connecting physics concepts with real-life situations. In addition, the learning process was still predominantly teacher-centered, while the learning resources used in the classroom mainly consisted of printed textbooks supported by PowerPoint presentations on limited occasions. These findings indicated the need for more interactive teaching materials that could facilitate creative problem solving through the integration of STEM principles.

Learner Analysis

The learner analysis showed that the participants were Grade XI science students aged between 16 and 17 years at SMA Negeri 3 Baubau. Although students were generally able to

answer routine questions presented by the teacher, many still encountered difficulties when solving contextual or analytical problems. This finding suggests that students' cognitive development, particularly in higher-order thinking skills, requires further support. A needs analysis conducted through a student questionnaire also revealed that 87.75% of students expected the use of an e-book as a learning medium. This result demonstrates a strong demand for digital learning resources that are more interactive and capable of supporting independent learning.

Task Analysis

The task analysis focused on identifying the learning outcomes that should be achieved through the developed e-book. Based on the curriculum analysis, the primary objective of the learning activities was to improve students' creative thinking abilities through contextual problem-solving activities integrated with the STEM approach.

Concept Analysis

The concept analysis identified temperature and heat as the focus of the learning materials. These concepts were selected because they represent fundamental topics in physics and serve as prerequisites for understanding more advanced concepts. The concept map developed from this analysis includes temperature, thermal expansion, heat, and heat transfer, which were subsequently organized into a coherent learning sequence within the e-book.

Formulation of Learning Objectives

The learning objectives were formulated according to the curriculum, the characteristics of the learning materials, and the number of instructional meetings. The objectives were organized into two learning sessions, each containing specific competencies and indicators that guided the design of learning activities and assessment.

Design

At the design stage, the initial prototype of the STEM-based physics e-book was developed. The e-book was designed to provide a structured learning experience by integrating learning materials with contextual activities based on the STEM approach. The prototype consists of a cover page, navigation menu, introduction, learning activities, student worksheets (LKPD), evaluation section, conclusion, bibliography, glossary, and author profile. The overall appearance of the initial prototype is presented in Figure 1.

Cover

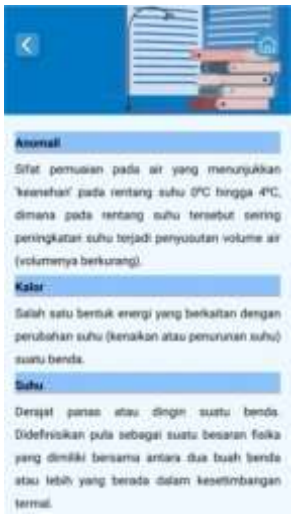
Menu Page and Buttons to Materials

Temperature and Heat Material

Button Display Evaluation

LKPD

Bibliography



Glossary

Author Profile

FIGURE 1. Display of STEM-Based Physics E-book

Develop

Feasibility of STEM-Based Physics E-Book

The feasibility of the developed e-book was evaluated through expert validation involving both material experts and media experts. The assessment focused on the appropriateness of the learning content, the quality of media design, language, presentation, and technical aspects of the e-book. The validation results are summarized in Table 1.

TABLE 1. Feasibility of STEM-Based Physics E-Book

Evaluation	Average	Category
Material Aspect	3.88	Very Good
Media Aspects	3.91	Very Good

The results presented in Table 1 indicate that the STEM-based physics e-book achieved an average score of 3.88 for the material aspect and 3.91 for the media aspect, both of which fall within the very good category. These findings indicate that the developed e-book is suitable for classroom implementation.

Following the expert validation process, several revisions were made to improve the quality of the product before it was implemented in the classroom. The revisions included refining the presentation of learning materials to improve conceptual clarity, simplifying several instructional sentences to enhance readability, improving the consistency of illustrations and layout, revising the navigation buttons for easier access, and adding clearer instructions to the student worksheets (LKPD). In addition, several contextual examples related to temperature and heat were refined to better represent the integration of science, technology, engineering, and mathematics (STEM) in problem-solving activities. These improvements were made based on experts' recommendations to ensure that the e-book was pedagogically appropriate and user-friendly.

Feasibility of Student Response Questionnaire

The feasibility of the student response questionnaire was evaluated before being used during the product trial. The questionnaire was designed to measure students' perceptions of the developed e-book in terms of content, construction, and language quality. The validation results are presented in Table 2**.**

TABLE 2. Feasibility of Student Response Questionnaires

No	Aspect	Mark	Category
1	Contents	4.00	Very Good
2	Construction	4.00	Very Good
3	Language	4.00	Very Good
	Average	4.00	Very Good

As shown in Table 2, all assessed aspects obtained an average score of 4.00, indicating that the questionnaire possesses excellent content quality and can be used to collect students' responses during the implementation of the STEM-based physics e-book.

Practicality of the STEM-Based Physics E-Book

The practicality of the developed e-book was assessed by physics teachers acting as practitioner validators. The assessment covered four aspects: usefulness, ease of use, ease of learning, and user satisfaction. The results are presented in Table 3.

TABLE 3. Practicality of the STEM-Based Physics E-Book

No	Aspect	Mark	Category
1	Usefulness	3.67	Very Good
2	Ease of Use	3.70	Very Good
3	Ease of learning	4.00	Very Good
4	User Satisfaction	3.75	Very Good
	Average	3.78	Very Good

The results in Table 3 show that all assessed aspects were categorized as very good, with an overall average score of 3.78. These findings indicate that the developed STEM-based physics e-book is practical to use in classroom learning. According to the practitioners, the e-book is easy to operate, supports the learning process effectively, and provides learning activities that are relevant to the characteristics of physics instruction on temperature and heat. Therefore, the developed e-book is considered suitable for implementation in physics learning.

Empirical Test of the Instrument

Before being administered in the field trial, the creative thinking abilities test underwent both content validation and empirical testing to ensure that the instrument was appropriate for measuring students' creative thinking abilities. Content validity was evaluated by experts, whereas empirical testing was conducted to examine the quality of the test items and the reliability of the instrument.

The content validity of the instrument was assessed using Aiken's V based on evaluations provided by expert lecturers, physics teachers as practitioners, and peer reviewers. The validation focused on the relevance of each item to the indicators of creative thinking abilities, the clarity of language, and the appropriateness of the content with the learning objectives. An item was considered valid when its Aiken's V coefficient was greater than 0.89.

After the content validation process was completed and the necessary revisions had been made, the instrument was empirically tested involving 262 Grade XII students from SMAN 1 Baubau, SMAN 3 Baubau, and SMAN 4 Baubau. The empirical test aimed to examine the compatibility of each test item with the measurement model and to estimate the reliability of the instrument. Item analysis was performed using the QUEST program, which was employed to evaluate item fit and estimate the reliability of the creative thinking Abilities test.

The results of the content validity analysis are presented in Table 4.

TABLE 4. Test Question Validation Results

No. Question Item	Aiken's V Value	Information
Creative Thinking Abilities Questions		
Item 1	1.00	High Validity
Item 2	1.00	High Validity
Item 3	0.94	High Validity
Item 4	0.94	High Validity
Item 5	0.94	High Validity
Item 6	1.00	High Validity
Item 7	0.94	High Validity

Item 8	1.00	High Validity
Item 9	0.89	High Validity
Item 10	0.94	High Validity
Item 11	1.00	High Validity
Item 12	1.00	High Validity
Item 13	1.00	High Validity
Item 14	0.94	High Validity
Item 15	0.94	High Validity
Item 16	0.94	High Validity
Item 17	0.94	High Validity
Item 18	1.00	High Validity

As shown in Table 4, all eighteen items achieved Aiken's V coefficients ranging from 0.89 to 1.00, indicating high content validity. These results demonstrate that each test item was considered relevant to the measured indicators and appropriate for assessing students' creative thinking abilities.

The reliability analysis obtained from the empirical test using the QUEST program is presented in Table 5.

TABLE 5. Reliability of Test Question Instruments

Test	Aspect	Mark	Category
Creative Thinking Abilities	Summary of item estimates	0,76	Reliable
	Summary of case estimates	0,80	Reliable

The results presented in Table 5 indicate that the creative thinking abilities instrument possesses satisfactory reliability. The reliability coefficient for the summary of item estimates was 0.76, while the summary of case estimates reached 0.80, both of which fall within the reliable category. These findings indicate that the instrument consistently measures students' creative thinking abilities on the topic of temperature and heat and is therefore appropriate for use in the field implementation of this study.

Disseminate

The final stage of the development process was dissemination, which aimed to introduce the validated STEM-based physics e-book to a broader group of users. After completing the define, design, and develop stages, and after revising the product based on expert recommendations, the e-book was considered suitable for classroom implementation.

The dissemination process began by providing access to the e-book through an application link that was distributed to physics teachers and Grade XI students at SMA Negeri 3 Baubau. This allowed teachers and students to use the e-book as a digital learning resource during physics instruction. To extend its utilization, the developed e-book was subsequently introduced to other senior high schools, including SMA Negeri 1 Baubau and SMA Negeri 4 Baubau. Furthermore, the development results were disseminated through publication in a scientific journal so that the e-book could serve as a reference for educators and researchers interested in developing STEM-based digital learning materials.

Product Trial Results

Limited Trial

A limited trial was conducted involving 30 students to evaluate the practicality and readability of the developed STEM-based physics e-book before it was implemented in the field trial. Students were asked to assess several aspects of the e-book, including presentation, language, graphics, media operation, and overall usefulness. The results of the limited trial are presented in Table 6.

TABLE 6. Student Responses to the Limited Trial

No	Aspect	Mark	Category
1	Presentation	3.54	Very Good
2	Linguistics	3.38	Good
3	Graphics	3.53	Very Good
4	Media Operations	3.62	Very Good
5	Benefit	3.67	Very Good
	Average	3.55	Very Good

Based on Table 6, the developed e-book obtained an overall average score of 3.55, which falls within the very good category. Among the assessed aspects, usefulness received the highest score (3.67), indicating that students perceived the e-book as beneficial for supporting their learning. Although the language aspect obtained a slightly lower score (3.38), it remained within the good category and did not reduce the overall quality of the product. These findings indicate that the STEM-based physics e-book met the practicality requirements and was suitable for implementation in the field trial after minor revisions suggested by the participants.

Field Trial

Following the limited trial, the revised STEM-based physics e-book was implemented in a field trial to examine students' responses after its use in classroom learning. The results of the student response questionnaire are presented in Table 7.

TABLE 7. Student Responses to the Field Trial

No	Aspect	Mark	Category
1	Presentation	3.72	Very Good
2	Linguistics	3.55	Very Good
3	Graphics	3.64	Very Good
4	Media Operations	3.72	Very Good
5	Benefit	3.46	Very Good
	Average	3.62	Very Good

The results presented in Table 7 show that the overall average student response reached 3.62, which is categorized as very good. All evaluated aspects received positive ratings, indicating that students considered the developed e-book to be attractive, easy to use, and beneficial during the learning process. Compared with the limited trial, several aspects showed slight improvements, particularly presentation quality and language, suggesting that the revisions made after the limited trial successfully enhanced the quality of the developed e-book. Therefore, the STEM-based physics e-book was considered appropriate for classroom implementation.

Pretest-Posttest Results of Creative Thinking Abilities

Students' creative thinking abilities was measured using an 18-item reasoned multiple-choice test administered before (pretest) and after (posttest) the learning intervention. Descriptive statistics of students' creative thinking scores are presented in Table 8.

TABLE 8. Results of Pretest-Posttest of Creative Thunking Abilities

Test	Class	Average	Tighest	Lowest	Standard Deviation
Pretest Creative Thinking Abilities	Experimen	59.27	78	40	9.12
	Control I	57.47	74	42	8.94
	Control II	57.84	85	39	9.77
Posttest Creative Thinking Abilities	Experimen	80.23	96	63	8.33
	Control I	73.63	88	53	9.28
	Control II	72.39	90	49	10.46

As presented in Table 8, the average pretest scores of all three classes were below the school's minimum mastery criterion (75), indicating that students had not yet mastered the concepts of temperature and heat before the intervention. This finding is reasonable because the learning material had not been introduced prior to the pretest.

After the learning intervention, the average posttest scores increased in all groups. The experimental class obtained the highest average score (80.23), followed by Control Class I (73.63) and Control Class II (72.39). Likewise, the highest individual posttest score was achieved by students in the experimental class. These findings indicate that learning using the STEM-based physics e-book resulted in greater improvement in students' creative thinking abilities than learning with either the non-STEM e-book or the printed textbook.

Statistical Test Results

Results of the First Hypothesis

The first hypothesis was tested to determine whether significant differences existed between students' pretest and posttest creative thinking scores across the three learning groups. The analysis was performed using the Tests of Within-Subjects Effects in the Mixed Design GLM. Because the assumption of sphericity was not fully satisfied, the Greenhouse–Geisser correction was applied. The results are presented in Table 9.

TABLE 9. Results of Test of Within-Subject Effect Output

Source		Measure	F	Sig.
Time*Class	Greenhouse-Geisser	Creative Thinking Abilities	3.584	0.031

As shown in Table 9, the interaction between time and class produced a significance value of 0.031, which is lower than the significance level of 0.05. These results indicate that changes in students' creative thinking scores from pretest to posttest differed significantly among the three learning groups. Consequently, further analyses were conducted to determine the magnitude of improvement within each group.

Results of the Second Hypothesis

The second hypothesis examined whether students in each learning group experienced significant improvement in creative thinking abilities after the learning intervention. The analysis was conducted using Pairwise Comparisons, and the results are presented in Table 10.

TABLE 10. Pairwise Comparisons Results

Variabel	Class	(I) Time	(J) Time	M.D (I-J)	Sig.
Creative Thinking Abilities	Experimen	Pretest	Posttets	-20.967	0.000
	Control I	Pretest	Posttets	-16.167	0.000
	Control II	Pretest	Posttets	-14.548	0.000

The results in Table 10 indicate that all learning groups experienced statistically significant improvements in creative thinking abilities, as evidenced by significance values below 0.05. The largest mean difference was observed in the experimental class (MD = –20.967), followed by Control Class I (MD = –16.167) and Control Class II (MD = –14.548). The negative mean difference values indicate that students' posttest scores were higher than their pretest scores. These findings demonstrate that learning activities in all three groups contributed to improvements in creative thinking abilities, although the magnitude of improvement varied according to the learning media used.

To determine whether these improvements differed significantly between groups, a post hoc analysis using the Bonferroni procedure was subsequently performed.

Post Hoc Analysis

The results of the Bonferroni multiple comparison test are presented in Table 11.

TABLE 11. Results of Post Hoc Multiple Comparisons Bonferroni Type

Variabel	(I) Class	(J) Class	M.D (I-J)	Sig.
Creative Thinking Abilities	Experimen	Control I	4.200	0.139
		Control II	4.640	0.081
	Control I	Experimen	-4.200	0.139
		Control II	0.440	1.000
	Control II	Experimen	-4.640	0.081
		Control I	-0.440	1.000

Based on Table 11, none of the pairwise comparisons reached the 0.05 significance level. The comparison between the experimental class and Control Class I yielded a significance value of 0.139, while the comparison between the experimental class and Control Class II produced a significance value of 0.081. Because both significance values are greater than 0.05, these differences cannot be considered statistically significant.

Although the experimental class obtained higher mean posttest scores than both control groups, the Bonferroni post hoc analysis indicates that these differences were not statistically significant. Therefore, the findings suggest that the STEM-based physics e-book tended to produce higher creative thinking scores; however, its superiority over the comparison groups could not be confirmed statistically based on the post hoc analysis. This interpretation is consistent with the reported significance values and should be considered when interpreting the effectiveness of the developed e-book.

Effective Contribution

The effectiveness of each learning medium was further examined using the General Linear Model (GLM) by analyzing the partial eta squared values obtained from the Hotelling's Trace multivariate test. The results are presented in Table 12.

TABLE 12. Multivariate Test Results (Hotelling's Trace)

Variabel	Class	F	Sig.	Partial Eta Squared
Creative Thinking Abilities	Experimen	139.912	0.000	0.614
	Control I	83.184	0.000	0.486
	Control II	69.609	0.000	0.442

The results presented in Table 12 show that the STEM-based physics e-book produced the largest effect size, with a partial eta squared value of 0.614, indicating that approximately 61.4% of the improvement in students' creative thinking abilities can be attributed to the learning treatment. Meanwhile, the e-book without STEM contributed 48.6%, whereas the printed textbook contributed 44.2%.

These findings suggest that integrating STEM into the e-book provides greater opportunities for students to engage in contextual problem solving, connect scientific concepts with real-world situations, and develop creative solutions through inquiry and engineering design activities. Nevertheless, although the STEM-based e-book demonstrated the largest practical effect, the Bonferroni post hoc analysis indicated that not all pairwise comparisons between groups reached statistical significance. Therefore, the effectiveness of the developed e-book should be interpreted by considering both the effect size and the results of the statistical significance tests.

Improvement in Students' Creative Thinking Abilities

Experimental Class Using the STEM-Based Physics E-book

Students' creative thinking abilities was assessed using 18 reasoned multiple-choice items representing four indicators of creative thinking: fluency, flexibility, originality, and elaboration. During the learning process, students in the experimental class used the STEM-based physics e-book as the primary learning resource. Changes in each aspect of creative thinking before and after the intervention are presented in Figure 2.

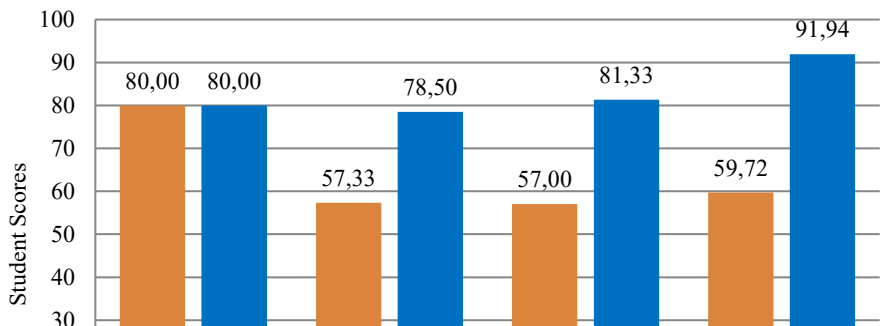


FIGURE 2. Improvement of Students' Creative Thinking Abilities in Each Aspect in the Experimental Class

Figure 2 shows that all aspects of students' creative thinking abilities improved after learning with the STEM-based physics e-book. This improvement indicates that the learning activities embedded in the e-book successfully engaged students in exploring concepts through contextual problems and guided them through a structured problem-solving process. The findings are consistent with previous studies reporting that STEM-based teaching materials integrated with Problem-Based Learning (PBL) can improve students' learning outcomes and creative thinking abilities (Maulidia et al., (2019; Dewi et al., 2020).

Among the four aspects, elaboration showed the largest improvement (32.22). This result can be explained by the design of the e-book, which encourages students to analyse problems in depth, explain their reasoning, and refine their proposed solutions through a sequence of STEM learning activities. Students were not only required to identify solutions but also to justify, develop, and communicate their ideas in greater detail. Such learning experiences encourage students to expand their explanations and connect scientific concepts with real-life situations. Previous studies have similarly reported that contextual investigations and engineering design activities stimulate students to elaborate their ideas more comprehensively (Sukmagati et al., 2020; Putri et al., 2020).

In contrast, the fluency aspect showed the smallest improvement. Fluency reflects students' ability to generate multiple ideas or alternative solutions within a limited period. The relatively small increase suggests that many students were still unfamiliar with producing numerous ideas independently because previous classroom instruction had primarily emphasized obtaining a single correct answer. Although the STEM-based e-book provided opportunities for idea generation, students still required more practice and teacher guidance to develop greater fluency in expressing diverse solutions. Therefore, learning activities that repeatedly encourage brainstorming and open-ended discussions may further strengthen this aspect of creative thinking.

Control Class I Using the Physics E-Book without STEM

Students in Control Class I learned using a physics e-book without STEM integration. Improvements in each aspect of creative thinking are presented in Figure 3.

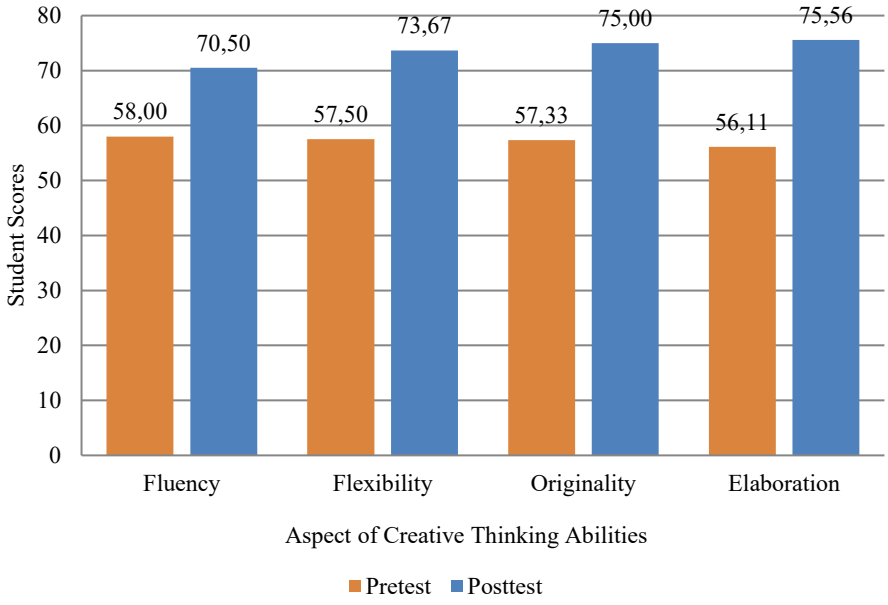


FIGURE 3. Improvement of Students' Creative Thinking Abilities in Each Aspect in Control Class I

As shown in Figure 3, students' creative thinking abilities also improved across all measured aspects after the learning activities. However, the magnitude of improvement was generally lower than that observed in the experimental class. The highest increase occurred in the elaboration aspect (19.45), while the fluency aspect showed the smallest improvement (12.50).

Although the non-STEM e-book provided students with digital learning materials that supported concept understanding, it did not explicitly integrate contextual problem solving, engineering design, and interdisciplinary STEM activities. Consequently, students had fewer opportunities to investigate authentic problems, design solutions, and evaluate alternative ideas systematically. As a result, the development of creative thinking, particularly fluency, was less pronounced than in the experimental class.

Control Class II Using the Printed Textbook

Students in Control Class II learned using the printed physics textbook commonly used in school. Improvements in each aspect of creative thinking are presented in Figure 4.

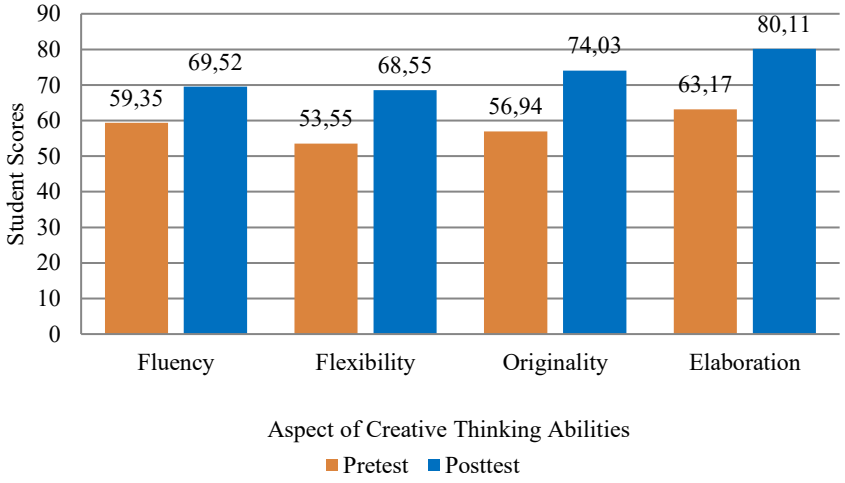


FIGURE 4. Improvement of Students' Creative Thinking Abilities in Each Aspect in Control Class II

Figure 4 indicates that all aspects of creative thinking improved after the learning process. Similar to the other groups, the elaboration aspect achieved the greatest increase (16.94), whereas fluency showed the smallest improvement (10.17).

The relatively lower improvement can be attributed to the characteristics of the printed textbook, which primarily emphasizes conceptual understanding rather than active problem solving. Students had limited opportunities to explore contextual situations, develop engineering solutions, or evaluate multiple alternatives. Consequently, learning activities tended to focus on mastering concepts instead of fostering higher-order thinking skills, resulting in smaller gains in creative thinking compared with the experimental class.

Overall, students who learned using the STEM-based physics e-book achieved the greatest improvement in creative thinking abilities. This finding suggests that integrating science, technology, engineering, and mathematics into digital learning materials provides richer learning experiences than using conventional learning resources alone. Through contextual problems, engineering design activities, and structured problem-solving tasks, students are encouraged to analyse situations from multiple perspectives, generate alternative solutions, and communicate their reasoning more effectively. These findings support previous studies indicating that STEM-based learning promotes meaningful learning experiences and strengthens students' creative thinking abilities (Han et al., 2015; Putri et al., 2020; Alatas & Yakin, 2021; Mulyana et al., 2018).

Nevertheless, the results of the Bonferroni post hoc analysis showed that the differences between the experimental class and the comparison groups were not statistically significant at the 0.05 level. Therefore, although the STEM-based physics e-book demonstrated the highest average improvement and the largest practical effect size, these findings should be interpreted cautiously because not all pairwise comparisons reached statistical significance. This indicates that the developed e-book has strong potential to improve creative thinking abilities, but further studies involving larger samples and longer implementation periods are needed to confirm its superiority statistically.

From a practical perspective, the STEM-based physics e-book can be implemented effectively when teachers facilitate learning through collaborative discussions, contextual

problem-solving activities, and guided investigations rather than relying solely on independent reading. The student worksheets (LKPD) embedded in the e-book should be used to encourage students to analyse problems, design alternative solutions, evaluate the feasibility of their ideas, and reflect on the learning process. Providing regular opportunities for brainstorming, group discussions, and classroom presentations is also recommended to further improve the fluency and originality aspects of students' creative thinking.

Discussion

The findings of this study indicate that the STEM-based physics e-book contributed positively to improving students' creative thinking abilities, particularly in learning the topic of temperature and heat. The effectiveness of the developed e-book is closely related to its instructional design, which integrates the principles of Science, Technology, Engineering, and Mathematics (STEM) into a series of contextual learning activities. Unlike conventional digital teaching materials that mainly present theoretical content, the developed e-book provides interactive learning experiences through the integration of images, learning videos, student worksheets (LKPD), investigation activities, evaluation tasks, and user-friendly navigation. These features encourage students to become actively involved in constructing knowledge rather than merely receiving information.

The STEM components were embedded throughout the learning activities in a systematic manner. The science component was implemented by guiding students to understand the concepts of temperature, heat, thermal expansion, and heat transfer through scientific explanations and investigations of everyday phenomena. The technology component was represented through the use of digital media, interactive learning resources, videos, and simulations available within the e-book. The engineering component required students to analyse contextual problems, design alternative solutions, and evaluate the feasibility of their proposed ideas through the activities provided in the student worksheets (LKPD). Meanwhile, the mathematics component was incorporated by engaging students in quantitative calculations, data interpretation, graphical analysis, and mathematical reasoning related to temperature and heat. The integration of these four components enabled students to connect scientific concepts with real-world situations while developing higher-order thinking skills.

The learning activities presented in the e-book were also designed by integrating the STEM approach with the syntax of Problem-Based Learning (PBL). The learning process began by presenting contextual problems related to temperature and heat that encouraged students to identify issues encountered in daily life. Students were then guided to investigate the causes of the problems by exploring relevant scientific concepts, collecting information, and discussing possible explanations. Based on the investigation results, students designed and evaluated alternative solutions by applying engineering principles and mathematical reasoning before communicating and reflecting on the solutions they had developed. Through these sequential activities, students were encouraged to analyse problems critically, generate creative ideas, and justify their reasoning systematically.

These findings support previous studies reporting that STEM-based learning provides meaningful learning experiences by encouraging students to relate scientific concepts to authentic situations (Putri et al., 2020). Similarly, Han et al., 2015 reported that STEM learning promotes creativity by engaging students in solving open-ended problems through collaborative and individual activities. Furthermore, contextual learning integrated with STEM has been shown to improve students' conceptual understanding and creative thinking because students

actively construct knowledge through investigation, design, and reflection rather than relying solely on teacher explanations (Alatas & Yakin, 2021; Mulyana et al., 2018).

The present findings also demonstrated that the STEM-based physics e-book produced the largest practical contribution to improving creative thinking abilities compared with the non-STEM e-book and the printed textbook. However, the results of the Bonferroni post hoc analysis indicated that not all pairwise comparisons between groups reached statistical significance. Therefore, although the STEM-based e-book showed a greater tendency to improve students' creative thinking abilities, these findings should be interpreted with caution. Future studies involving larger samples, longer intervention periods, and broader implementation contexts are needed to further confirm the effectiveness of the developed e-book.

From a practical perspective, the developed e-book can serve as an alternative digital teaching material for physics teachers, particularly when teaching temperature and heat. To maximise its effectiveness, teachers should facilitate collaborative discussions, guide students through each stage of STEM-based problem solving, and encourage reflection after completing investigation and engineering activities. The student worksheets (LKPD) should not only be used as written assignments but also as tools to stimulate scientific inquiry, engineering design, and collaborative problem solving. Continuous teacher guidance is particularly important to encourage students to generate multiple ideas, evaluate alternative solutions, and communicate their reasoning, thereby supporting the development of all aspects of creative thinking.

CONCLUSION

Based on the results of this research and development study, it can be concluded that the STEM-based physics e-book developed for the topic of temperature and heat met the criteria of high feasibility, as indicated by the evaluations of material and media experts. In addition, the e-book demonstrated a high level of practicality based on the responses of both students and physics teachers, indicating that it is appropriate for use as a digital learning resource in physics instruction.

The implementation of the STEM-based physics e-book was associated with improvements in students' creative thinking abilities. Students who learned using the STEM-based e-book achieved higher average posttest scores and the largest practical effect size (61.4%) compared with the groups using the non-STEM e-book and the printed textbook. However, the results of the Bonferroni post hoc analysis indicated that the differences between groups did not reach statistical significance in all pairwise comparisons. Therefore, the findings suggest that the STEM-based physics e-book has the potential to support the development of students' creative thinking abilities, but its effectiveness relative to other learning media should be interpreted cautiously and in accordance with the statistical evidence obtained.

From a practical perspective, the developed e-book can be used by physics teachers as an alternative digital teaching material to support learning on temperature and heat. The integration of contextual problems, STEM activities, and student worksheets (LKPD) enables teachers to facilitate inquiry, collaborative learning, and structured problem-solving processes that encourage the development of students' creative thinking abilities.

This study has several limitations. The participants were limited to selected senior high schools in Baubau, and the use of a quasi-experimental design did not allow for complete random assignment of participants. In addition, differences in teacher implementation during

classroom instruction may have influenced students' learning outcomes. Therefore, the findings should be generalized with caution.

Future studies are recommended to involve larger and more diverse samples from different regions, apply randomized or matched-class experimental designs, extend the duration of implementation, and evaluate creative thinking using additional indicators such as students' project outcomes, engineering products, and creative problem-solving processes, in addition to written test scores.

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