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DEVELOPMENT OF GUIDED INQUIRY-BASED E-LKPD TO IMPROVE CRITICAL THINKING ABILITY AND MATHEMATICAL REPRESENTATION

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Abstract :
An e-LKPD based on guided inquiry has been developed using Liveworksheets on heat and its transfer. The primary objective of this paper is to generate an inquiry-based e-LKPD that is demonstrably feasible, practical, and effective in enhancing students' critical thinking ability and mathematical representation. The methodology adopted for this development study adheres to the ADDIE model. The sampling procedure employed in the study used cluster random sampling. Data acquisition was carried out using both testing and non-testing instruments. For the analysis of the gathered data, several techniques were applied: Aiken's V statistic was used to validate the instruments, SBI was applied to the student response questionnaires, and the effectiveness analysis used MANOVA and GLM. This study's main results are: (1) the inquiry-based e-LKPD utilizing Liveworksheet is suitable for deployment in advancing critical thinking and mathematical representation, as confirmed by assessments from expert validators, practitioners, and peers; (2) the developed e-LKPD is operationally practical for fostering these skills, evidenced by feedback collected through student response questionnaires concerning the learning medium; (3) the inquiry-based e-LKPD is demonstrably effective in enhancing students' critical thinking and mathematical representation, based on the improvement observed in students' pre-test and post-test scores following the use of the developed resource. A distinctive feature of this research lies in the seamless integration of the guided inquiry e-LKPD with the Liveworksheet. This integration allows students to access the learning materials at any time, thereby contributing to the advancement of their critical thinking and mathematical representation skills.

Keywords: e-LKPD, Critical Thinking, Mathematical Representation

INTRODUCTION

The global educational landscape has experienced significant changes, driven by the rapid advances of the 21st century, necessitating its adaptation to the increasingly dynamic and intricate demands of the current era. Contemporary education transcends mere knowledge transmission; it now prioritizes the cultivation of essential 21st-century competencies (Putri et al., 2024). As outlined by the 21st Century Partnership Learning Framework, several key abilities must be nurtured among learners: (1) critical thinking and issue resolution, (2) proficiency in communication and teamwork, (3) aptitude for creativity and novel ideas, (4) mastery of information and communication technology (ICT) literacy, (5) competence in learning within context, and (6) expertise in information and media literacy (Jayadi et al., 2020). Acquiring these proficiencies is vital for successfully navigating the challenges and complexities characteristic of this century (Redhana, 2019). Consequently, the integration and development of these aforementioned skills are crucial during instruction, ensuring that students are adequately prepared to meet the multifaceted demands of the 21st century.

One important skill students must have in 21st-century learning is critical thinking. Critical thinking skills can prepare students to think about various fields of knowledge (Melie, 2024), prepare them for intellectual acculturation (Putri et al., 2021), and develop them into individuals with the potential to survive in the 21st century (Annisa & Asrizal, 2022). Critical thinking is an activity in the learning process in which students are actively and diligently involved in understanding information. The characteristics of critical thinking in students include asking questions and raising issues, collecting and assessing relevant information, drawing conclusions with strong reasoning, and overcoming confusion (Kholid, 2024).

The necessity of critical thinking competence for success in the 21st-century educational landscape is inconsistent with the measured proficiency levels among Indonesian students. Physics instruction, which forms an integral component of science education, fundamentally relies on critical reasoning for deciphering cosmic phenomena (Gunada et al., 2023). Nevertheless, students' demonstrated critical thinking remains suboptimal (Nurjanah et al., 2022). Empirical findings from earlier studies underscore this deficit: students' ability to resolve physics challenges is classified as "low" at 53.6%. Specifically, the interpretation dimension was assessed as "very low" (20%), while the analysis (40%) and inference (41.94%) dimensions were rated as low (Asniar et al., 2022). Further research confirms this pattern, reporting specific weaknesses across different facets: interpretation (38.71%), analysis (58.06%), inference (41.94%), explanation (a mere 9.68%), and self-regulation (48.39%) (Benyamin et al., 2021). These collective findings from previous investigations consistently demonstrate that students' critical thinking capabilities are deficient, highlighting an issue that demands immediate intervention within the physics curriculum.

Several factors contribute to students' low critical thinking ability. One of them is the teacher-centered approach to learning, which makes students passive and unable to understand what is being taught (Walsh et al., 2022). When students are not actively involved in learning, they become accustomed to using only a small portion of their potential and tend to lack the development of critical thinking skills (Marni et al., 2020). Students' low critical thinking ability leads to their inability to solve problems in physics.

In addition to critical thinking, students need to master representation in physics learning. In physics, mathematical representation includes describing variable values using equations and functions to explain the physical conditions of a phenomenon. Good mathematical ability makes it easier for students to understand quantities, symbols, and equations, enabling them to relate numbers to physical conditions. However, mathematical representation ability is currently still moderate to low, with a percentage of 38.62% (Sarizan et al., 2022). Other studies also show that students' mathematical representation skills are low (Muyassaroh & Waluya, 2023). The ability to reason, formulate, and solve problems in a mathematical context has not been fully achieved (Kusuma et al., 2021). In line with the research (Mataheru et al., 2021) students' mathematical representation ability is low, with a percentage of 17.61%. Therefore, it is very important to improve mathematical representation ability in physics learning.

Physics education constitutes a domain of study that is highly interconnected with the advancements characterizing the 21st century. Physics holds the distinction of being the most foundational discipline of science, primarily because of its focus on investigating the composition and behavior of matter (Giancoli, 2010). Furthermore, this scientific branch elucidates natural occurrences and the fundamental mechanisms by which nature operates (Khoiri et al., 2023). Physics is closely related to the universe, so students must understand the theories, laws, concepts, and facts discovered by scientists (Rosuli et al., 2019). The ability to understand physics concepts correctly will help students solve problems in physics learning (Taqwa et al., 2019). Physics material contains many abstract concepts that are difficult for students to understand (Khoiriyah & Suprapto, 2021). One topic in physics learning that requires critical thinking and mathematical representation is heat and its transfer.

Heat and heat transfer are often considered complex topics. Research shows that 5.26% of students understand the concept, 55.26% have misconceptions, 31.59% lack knowledge, and 7.89% give incorrect answers (Purwanto & Winarti, 2020). Other studies also show that students have difficulty understanding questions (80.3%), using symbols (76.2%), using formulas (84%), analyzing graphs (65%), and performing calculations (90%) (Charli et al., 2018). Students still have difficulty analyzing heat transfer through the properties of an object that are influenced by the conductivity value of a material (Laili et al., 2021). One way to improve students' critical thinking and mathematical representation skills in heat and heat transfer materials is to use effective learning media and models.

With the rapid development of technology, physics education must keep pace by utilizing tools that facilitate student learning and make it easier for teachers to teach physics material. In the material on heat and its transfer, learning media is needed that can simultaneously improve critical thinking and mathematical representation ability, so that the application of e-LKPD becomes a choice for developing learning media that aims to improve students' critical thinking and mathematical representation ability. This is in line with research by Suryaningsih and Nurlita (2021) that states that the advantage of e-LKPD as a learning medium is to increase students' interest in learning and reduce boredom during the learning process. In addition, research on e-LKPD shows that this format speeds up access to certain information and facilitates the learning process for students, which can improve students' understanding of the material in solving problems more critically and motivating students during learning (Savira et al., 2023). The application of e-LKPD can improve students' critical thinking ability (Rudibyani, 2020). E-LKPD acts as teaching material that can minimize the role of teachers, but on the other hand, it can encourage students to be more active (Kinanti et al., 2024). One of the benefits of e-LKPD is that it can increase student engagement in the learning process (Prastowo, 2014). Thus, students' critical thinking ability will improve. In addition, e-LKPD has the advantage of facilitating learning because it can be accessed through various electronic devices such as desktops, computers, notebooks, and smartphones (Hidayah et al., 2020). The use of e-LKPD will increase students' motivation to learn.

In this study, researchers developed an electronic learning medium called e-LKPD. This e-LKPD was developed using the LiveWorksheet website, which helps teachers convert printed worksheets into online formats (Nirmayani, 2022). This platform is easily accessible via a link, allowing students to answer questions directly on the e-LKPD using personal devices such as mobile phones, laptops, computers, or tablets. In addition, this website is capable of automatic correction with fairly simple specifications (Sugiarni et al., 2023). This study aims to leverage technological and internet advances to make learning materials more visually appealing, interactive, and easily accessible, available anytime and anywhere.

One effective learning model for improving critical thinking and mathematical representation ability is the guided inquiry learning model. This is in line with research stating that guided inquiry is more effective than problem-solving and lecture methods in improving students' critical thinking ability (Putra, 2021). The guided inquiry model integrated into e-LKPD encourages students to be active and think critically in solving problems, as well as strengthening their ability to identify and critically assess information (Devi et al., 2022). Guided inquiry is an approach that allows students to build knowledge independently and deepen their understanding of the concepts being studied (Rambe et al., 2019). In this approach, teachers no longer function as the main source of information, but rather design learning plans or experimental steps, while students conduct investigations or experiments according to these plans (Anggraeni et al., 2019). By using the guided inquiry model, participants can be actively involved in the learning process.

RESEARCH METHOD

Research Design

This study uses qualitative and quantitative approaches. Qualitative data were collected in March 2025 at Yogyakarta State University. Meanwhile, quantitative data were collected in May at SMAN 4 Praya, Central Lombok, West Nusa Tenggara.

Research Target/Subject

The research subjects included expert lecturers, practitioners, and students. Qualitative data were obtained from comments or suggestions for improvement from expert lecturers, physics teachers, and colleagues. Quantitative data were obtained from assessment instruments for the feasibility of guided inquiry-based e-LKPD using the Liveworksheet website, teaching module feasibility instruments, and test question feasibility instruments for the developed products. The objects of study were the feasibility, practicality, and effectiveness of the product developed, based on product validation, empirical validation, and improvements in students' critical thinking and mathematical representation ability. The selection of test subjects was limited, and field tests used cluster random sampling. Random sampling techniques were chosen based on clusters, assuming that each group or individual has the same ability tendencies. This was determined based on interviews with physics teachers and final semester 1 assessment data, where each cluster showed similar or homogeneous tendencies.

Research Procedure

This research constitutes a Research and Development (R&D) project aimed at creating an e-LKPD. This resource is designed around the guided inquiry approach and utilizes the Liveworksheets. The primary goal of this development is to enhance students' proficiencies in critical thinking and mathematical representation. The ADDIE model, as introduced by (Branch, 2009), was selected as the framework guiding the product creation. This particular framework is structured into five sequential phases: analysis, planning, development, implementation, and evaluation.

Instruments and Data Collection Techniques

This study used both test and non-test data collection techniques. The test technique measured students' critical thinking and mathematical representation abilities through pre-tests and post-tests. The non-test technique gathered additional information for analysis and included observations, interviews, questionnaires, and documentation. The research instruments consisted of validation sheets for product feasibility, teaching modules, e-LKPD, and test items for critical thinking and mathematical representation. Experts validated all instruments, and once validated, the feasibility assessment sheets were used to evaluate the e-LKPD, teaching modules, and test items.

Data Analysis Technique

The methodology employed for data analysis was used to create an e-LKPD product. This specific product, which incorporates the guided inquiry model and is hosted on the Liveworksheet platform, was engineered to fully satisfy predefined standards regarding feasibility, practicality, and effectiveness. The information gathered throughout this investigation was categorized into two distinct forms: qualitative and quantitative measurements. Specifically, qualitative inputs were derived from feedback, commentary, and constructive suggestions from the panel of experts (including university lecturers and physics educators), peer reviewers, and student participants. Quantitative data were obtained from the e-LKPD-guided inquiry assessment instrument, the live-worksheet website, the teaching module assessment instrument, and the test question assessment instrument for the developed product.

RESULTS AND DISCUSSION

The framework utilized for product creation is the ADDIE approach, an acronym encompassing five distinct phases: Analysis, Design, Development, Implementation, and Evaluation.

Analysis

A preliminary analysis was conducted through observations and interviews to identify issues in the physics learning process at the school. The observation conducted in the school environment, the 11th-grade classroom, and through an interview with the physics teacher showed that the school's facilities, including the building, student potential, staff availability, library, and laboratory, were adequate and supportive of learning. However, classroom learning remained teacher-centered, relying mainly on lectures and discussions, with teaching materials limited to school textbooks. These methods made students less engaged, and the lecture approach was ineffective in enhancing their critical thinking skills. The interview with Fatya Kurniati, S.Si, a physics teacher at SMAN 4 Praya, confirmed that lectures were frequently used and that teaching materials were mainly drawn from Ministry of Education and Culture textbooks, although group discussions were occasionally used to increase student participation.

An analysis of the students was conducted to identify their characteristics, including age, abilities, and cognitive development. Classroom observations showed that some students struggled to focus and were often distracted by their own activities. The researcher also noted that students still had difficulty learning independently. Their critical thinking skills were relatively low, as evidenced by their performance on physics problems that required higher-level reasoning. In addition, their mathematical representation skills were weak, as evidenced by difficulties analyzing equations, describing problems mathematically, and solving physics tasks. A curriculum analysis was also conducted to determine the boundaries of learning outcomes, the sequences of objectives, and the key topics. The 11th-grade (Phase F) curriculum at SMAN 4 Praya follows the Independent Curriculum, which provides varied intracurricular activities that allow students more time to explore concepts and strengthen their abilities through projects. The researcher then analyzed the learning outcomes to develop learning objectives and indicators for a guided inquiry-based e-LKPD, created using LiveWorksheet, aimed at improving students' critical thinking and mathematical representation skills in the topic of heat and its transfer.

Concept analysis aims to identify the basic concepts in heat and heat transfer that will be taught in physics lessons. Concept analysis is based on facts, concepts, principles, and theories. The development of learning indicators continues to focus on critical thinking and mathematical representation ability as the competencies that students are expected to achieve. The development of testing instruments for heat and heat transfer materials aligns with critical thinking and mathematical representation abilities. Indicators for critical thinking ability are interpretation, analysis, evaluation, explanation, and conclusion. Meanwhile, indicators for mathematical representation ability are: (1) Modeling physics problems into mathematical symbols, (2) Solving physics problems using mathematical equations, and (3) Translating another representation into a mathematical representation.

Design

The planning stage produced teaching modules, an e-LKPD, and instruments for measuring critical thinking and mathematical representation abilities, along with validation sheets. The teaching modules were designed based on the Independent Curriculum and aligned with indicators of both abilities. The guided inquiry model was applied, following its syntax: problem identification, problem formulation, hypothesis development, data collection, data analysis, and conclusion. The e-LKPD was developed by reviewing the results of the preliminary and student analyses. It was designed to match students' needs, school conditions, and the topic of heat and its transfer. Liveworksheet was selected as the platform because it is easily accessible anytime and anywhere, supporting student learning. The development process began with the creation of a development guide, an e-LKPD outline, and a storyboard. The development guide outlined the definition, objectives, product specifications, operational definitions, dependent variables, and indicators used in developing the e-LKPD.

The assessment tools used to measure students' proficiency in critical thinking and mathematical representation were developed in an essay format. This design choice was made to streamline the evaluation of enhancements in these specific students' abilities within the subject of heat and its transfer. The evaluation of improvement was primarily based on a comparative analysis of the answers provided in the pre-test and post-test examinations. There are 10 critical thinking questions. Each question is used to measure one indicator of critical thinking ability. There are 6 mathematical representation questions. Each question is used to measure one indicator of mathematical representation ability. The pre-test questions are designed to measure students' initial abilities and consist of 5 critical thinking questions and 3 mathematical representation questions. The pre-test is conducted before the intervention is implemented. The post-test questions are given to measure the improvement in students' abilities after using the developed e-LKPD. The post-test consists of 5 critical thinking questions and 3 mathematical representation questions.

The non-test instruments produced include validation sheets. The validation sheets are intended for expert validators (physics professors), practitioner validators (physics teachers), and peer validators (master's students in physics education) to assess the suitability of e-LKPD through guided inquiry on the liveworksheet website. The validation sheets are also used to assess the suitability of teaching modules, critical thinking ability tests, and mathematical representation ability tests for students.

Development

The teaching module feasibility data were collected using a questionnaire on a 1-4 scale, with a column for comments and suggestions to improve the teaching module. 10 aspects were assessed. The results of the teaching module validation assessment are shown in Table 1.

Table 1. Results of the teaching module feasibility assessment

No	Aspect	Assessment results	Criteria
1.	General information teaching module	4.74	Very good
2.	Allocation of learning time	4.20	Very good
3.	Initial competencies	3.94	Very good
4.	Formulation of learning objectives	4.20	Very good
5.	Formulation of learning models	4.47	Very good
6.	Selection of teaching materials	4.20	Very good
7.	Selection of learning resources	4.19	Very good
8.	Learning steps	4.19	Very good
9.	Assessment of learning outcomes	3.94	Very good
10.	Language	3.81	Very good

Based on Table 1, every aspect of the teaching module feasibility assessment falls within a very good category. The assessment of the teaching module's suitability by 2 physics lecturers, 2 physics teachers, and 2 master's students in physics education overall falls into the “very good” category, with an average score of 4.16 across all aspects. Therefore, it can be concluded that the teaching module developed to support physics education is deemed suitable, but revisions are still needed based on the suggestions and comments from the validators. The feasibility results for guided inquiry-based e-LKPD using the liveworksheet website are shown in Table 2.

Table 2. Results of e-LKPD feasibility assessment

No	Aspect	Assessment results	Criteria
1.	Compliance of e-LKPD with the guided inquiry model	4.26	Very good
2.	Content and material	4.33	Very good
3.	e-LKPD design	4.23	Very good
4.	Language suitability	3.82	Very good
5.	Ease of use	4.12	Very good

The data presented in Table 2 demonstrate that every dimension of the feasibility evaluation for the guided inquiry-based electronic student worksheet (e-LKPD), which uses the Liveworksheet platform, falls within the 'Very Good' classification. Specifically, the comprehensive assessment conducted by six expert reviewers, comprising two physics academics (lecturers), two physics practitioners (teachers), and two postgraduate students in physics education, yielded an average aggregated score of 4.14, confirming the 'Very Good' standing across the board. Consequently, the developed e-LKPD is deemed appropriate for application, though minor adjustments are required based on the suggestions and constructive input provided by the evaluators. Furthermore, the validity results for the critical thinking and mathematical representation assessment tools were established by expert judges. The outcomes of this data collection instrument validation are comprehensively displayed in Tables 3 and 4.

Table 3. Results of the critical thinking ability assessment instrument

Items	Aiken's V	Criteria	Items	Aiken's V	Criteria
A1	0,78	Valid enough	B1	0,89	Valid
A2	0,78	Valid enough	B2	0,83	Valid
A3	0,83	Valid	B3	0,83	Valid
A4	0,89	Valid	B4	0,94	Valid
A5	0,89	Valid	B5	0,89	Valid

Table 4. Results of the mathematical representation ability assessment instrument

Items	Aiken's V	Criteria	Items	Aiken's V	Criteria
A1	0,83	Valid	B1	0,89	Valid
A2	0,83	Valid	B2	0,83	Valid
A3	0,89	Valid	B3	0,89	Valid

Note: A (pre-test questions), B (post-test questions)

Based on Aiken's V values for each item, it can be concluded that all items in the critical thinking and mathematical representation ability test instruments are valid.

Empirical testing was conducted to determine the characteristics of critical thinking and mathematical representation questions, namely their validity and reliability. This study used three schools with a total of 254 students to ensure that the test instrument data varied across students' ability levels. Ten items were used in the empirical test to measure critical thinking ability, and six items to measure mathematical representation ability. The empirical test provided information about the characteristics of each item, including the suitability of the items with the Partial Credit Model (PCM), which included INFIT MNSQ values, reliability, and item difficulty levels. The results of the empirical test analysis are described as follows.

The results of matching critical thinking and mathematical representation questions to the Partial Credit Model (PCM) can be seen in the QUEST software output, with file types ending in "sh.out," based on the INFIT MNSQ value. The results of the analysis of the matching between critical thinking and mathematical representation questions and the PCM are shown in Figures 1 and 2.

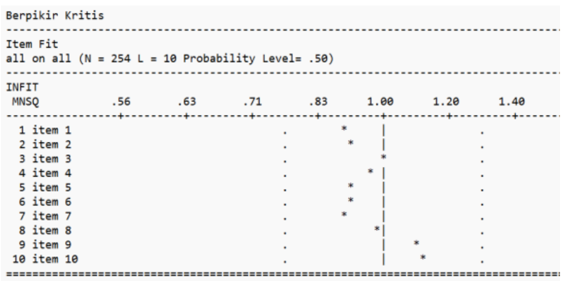

Figure 1. Matching critical thinking ability test items with the Partial Credit Model (PCM)

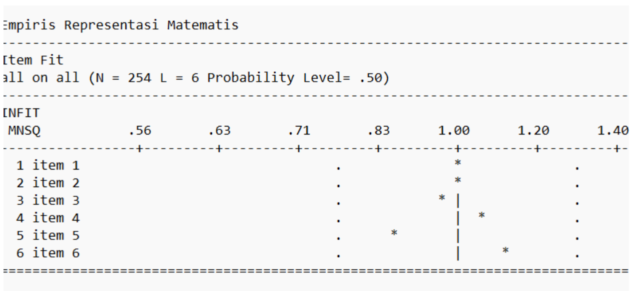

Figure 2. Matching of mathematical representation ability items with the Partial Credit Model (PCM)

Based on Figures 1 and 2, all critical thinking and mathematical representation questions fit the Partial Credit Model (PCM), with INFIT MNSQ values ranging from 0.77 to 1.33. Therefore, critical thinking and mathematical representation questions can be used in the research implementation stage. The reliability of the test instrument can be determined by examining the consistency of the scores obtained in measuring students' critical thinking and mathematical representation abilities. A high reliability score indicates that an instrument is more consistent for use in measurement. The results of the test instrument reliability analysis can be obtained by analyzing the “sh.out” output data using the QUEST program, based on the summary of item estimates and the summary of case estimates. The summary of item estimates is used to determine whether the items used are suitable for the Rasch model being tested, and this value is also referred to as sample reliability. Meanwhile, the summary of case estimates represents the reliability value for the test created. The reliability results for the critical thinking and mathematical representation ability test instruments are shown in Table 5.

Table 5. Reliability results of critical thinking and mathematical representation ability test

Variable	Reliability	Reliability value	Category
Critical Thinking	Summary of item estimates	0,83	Reliable
	Summary of case estimates	0,68	Reliable
Mathematical	Summary of item estimates	0,72	Reliable
Representation	Summary of case estimates	0,65	Reliable

Based on Table 5, the values of Summary of item estimates and Summary of case estimates for critical thinking ability and mathematical representation ability are reliable and therefore suitable for consistently measuring students' critical thinking ability and mathematical representation ability. The difficulty level of the questions analyzed through the QUEST program can be seen in the “it.out” data output. The difficulty level of the questions is shown in the difficulty column, which displays the delta value. The difficulty level of the questions ranges from -2.00 (very easy) to +2.00 (very difficult). The difficulty levels of the critical thinking and mathematical representation questions are shown in Tables 6 and 7.

Table 6. Results of the difficulty level of critical thinking ability questions

Question item	Delta value (b)	Category	Question item	Delta value (b)	Category
1	-1,33	Easy	6	-0,43	Moderate
2	-1,29	Easy	7	-0,81	Moderate
3	+0,76	Moderate	8	-0,67	Moderate
4	+0,93	Moderate	9	+1,56	Difficult
5	-0,20	Moderate	10	+1,49	Difficult

Based on Table 6, the critical thinking questions show a difficulty level ranging from -1.33 to +1.56. This indicates that the items fall within the range of -2.00 to +2.00, indicating good quality. Of the 10 items analyzed, item 9 has the most significant delta (b) value of 1.56, indicating that it falls into the difficult category. Meanwhile, item 1 has the smallest delta (b) value of -1.33, indicating that it falls into the easy category.

Table 7. Results of the difficulty level of mathematical representation ability questions

Question item	Delta value (b)	Category	Question item	Delta value (b)	Category
1	-1,10	Easy	4	-0,30	Moderate
2	-0,40	Moderate	5	+0,86	Moderate
3	-0,18	Moderate	6	+1,12	Difficult

Based on Table 7, the items on mathematical representation ability show a difficulty level ranging from -1.10 to +1.12. This indicates that the items fall within the range of -2.00 to +2.00, indicating good quality. Of the 10 items analyzed, item 6 has the most significant delta (b) value of +1.12, indicating that it falls into the difficult category. Meanwhile, item 1 has the smallest delta (b) value of -1.10, indicating that it falls into the easy category. The aspects of student response assessment consist of content, appearance, language, and usage. The student response results obtained are ordinal data, which are then converted into interval data using the Method of Successive Intervals (MSI). The results of the analysis of student responses to the e-LKPD are shown in Table 8.

Table 8. Results of analysis of student responses to e-LKPD

No	Aspect	Total average	Criteria	No	Aspect	Total average	Criteria
1.	Content	3,25	Good	3.	Language	3,29	Good
2.	Appearance	3,27	Good	4.	Usability	3,46	Good

Based on Table 8, it can be seen that every aspect of the students' responses to the Guided Inquiry-based e-LKPD using the liveworksheet website falls within a good category, so it can be concluded that the e-LKPD product is practical and can be used in physics learning.

Implementation

The implementation stage was marked by field tests conducted to assess the product's effectiveness, using pre- and post-test scores on students' critical thinking and mathematical representation ability. Field tests were conducted in three classes, one as an experimental class and two as contrast classes. The guided inquiry-based e-LKPD product was applied in the experimental class, while the two contrast classes used different models or methods. Research with the implementation of guided inquiry-based e-LKPD using the liveworksheet website was conducted in three learning sessions on the subject of heat and its transfer. The initial stage involved conveying the learning objectives. Then, all students took a pre-test to determine their initial understanding of heat and its transfer. The pre-test consisted of five questions to assess critical thinking ability and three questions to assess mathematical representation ability. After that, the teacher delivered the lesson by following the syntax of the guided inquiry learning model, which included introducing the problem, formulating hypotheses based on the existing problem statements, collecting and analyzing data, and drawing conclusions. After conducting learning by applying the guided inquiry learning model syntax, a post-test was conducted. The post-test consisted of 8 essay questions, 5 questions for critical thinking ability, and 3 questions for mathematical representation ability. Then, the pre-test and post-test results were analyzed to determine the effectiveness of the e-LKPD product developed. The results of the pre-test and post-test for critical thinking ability and mathematical representation ability of the students were analyzed using the N-Gain test, Prerequisite Test, MANOVA test, and GLM to determine the effectiveness of the guided inquiry-based e-LKPD using the liveworksheet website. Before conducting the MANOVA and GLM analyses, the N-gain and prerequisite tests were conducted.

a. N-gain results

The effectiveness of the developed guided inquiry-based e-LKPD (electronic Student Worksheet), which utilized the Liveworksheet website, was evaluated by comparing students' pre-test and post-test scores across the experimental group, contrast class 1, and contrast class 2. Furthermore, the level of students' critical thinking competency across these three distinct classes was established by calculating N-Gain scores for each corresponding variable. Detailed figures on critical thinking proficiency are presented in Table 9.

Table 9. Critical thinking ability results

No	Class	N	Average critical thinking ability		N-Gain	Category
			Pre-test	Post-test		
1.	Experiment	36	20,83	82,22	0,78	high
2.	Contrast 1	36	19,31	70,69	0,63	Moderate
3.	Contrast 2	36	18,61	66,53	0,59	Moderate

The average pre-test score for critical thinking skills in the experimental group was the highest, followed consecutively by contrast class 1 and contrast class 2. Subsequently, post-treatment evaluation revealed that the experimental group also achieved the maximum mean post-test score, once again trailed by contrast classes 1 and 2. Specifically, the experimental group recorded a pre-test mean of 20.83, which rose to 82.22 on the post-test, indicating a pronounced improvement in students' critical thinking competency. Conversely, contrast class 1 showed an increase from a pre-test mean of 19.31 to a post-test mean of 70.69, while contrast class 2 improved from 18.61 to 66.53. These latter results suggest an improvement in student critical thinking, albeit a less substantial one.

The efficacy of the developed e-LKPD (electronic Student Worksheet) that employs guided inquiry via the Liveworksheet platform was quantified by analyzing students' pre- and post-test scores concerning their mathematical representation proficiency across all three groups: the experimental class, contrast class 1, and contrast class 2. The level of development in mathematical representation ability for each class was subsequently established using the N-Gain scores calculated for the respective variable. Detailed findings regarding mathematical representation competence are accessible in Table 10.

Table 10. Results of mathematical representation ability

No	Class	Number of students	Average ability		N-Gain	Category
			Pre-test	Post-test		
1.	Experiment	36	31,94	81,02	0,74	High
2.	Contrast 1	36	28,70	69,68	0,58	Moderate
3.	Contrast 2	36	29,63	67,59	0,54	Moderate

Based on Table 10, the mean competence level in mathematical representation during the initial assessment (pre-test) was led by the experimental group, followed sequentially by contrast class 2 and contrast class 1. Following the intervention (treatment), the experimental group achieved the highest mean score on the final assessment (post-test) for this ability, with contrast class 1 and contrast class 2 trailing behind. Specifically, the experimental group's average mathematical representation score escalated dramatically from 31.94 on the pre-test to 81.02 on the post-test, underscoring a marked improvement in the students' capabilities. Conversely, contrast class 1 recorded pre-test and post-test averages of 28.70 and 69.68, respectively, while class 2 recorded 29.63 (pre-test) and 67.59 (post-test). While some improvement in mathematical representation competence was observed relative to class 2 students, the extent of this gain was not substantial.

b. Preliminary Test

The effect of using guided inquiry-based e-LKPD with the liveworksheet on students' critical thinking and mathematical representation ability was analyzed using MANOVA, as there were two dependent variables: critical thinking ability and mathematical representation ability. Nine assumptions were tested before the MANOVA analysis, and assumptions 1, 2, 3, and 4 were assessed without statistical testing. The assumption tests are as follows:

The data has two dependent variables and is on an interval or ratio scale. This assumption is met because the study's dependent variables are critical thinking and mathematical representation. The data is on a ratio scale. There are two or more treatments that influence the dependent variable. This study uses three classes with different treatments. The three classes consist of an experimental class and two contrast classes: class 1 and class 2. The experimental class received a guided inquiry-based e-LKPD learning treatment using the Liveworksheet website. Contrast class 1 used the guided inquiry model. Contrast class 2 used the Ministry of Education and Culture's physics textbook for the independent curriculum. Thus, assumption 2 is fulfilled. Observation independence data. This assumption holds because there is no relationship between observations within each group. Sufficient sample size. This assumption is met because the study used 108 samples, with 36 per class. There were no univariate outliers in either group. The assumption of outliers is evident in Table 23, the residual statistics. Decisions were made based on Mahalanobis Distance values. The Mahalanobis distance values are shown in Table 11.

Table 11. Residual statistics

Mahal Distance	Minimum	Maximum	Mean	Std. Dev	N
	0,20	6,28	0,99	1,117	108

Based on Table 11, the maximum distance value is 6.28. This indicates that the maximum value is less than the critical value (13.82), so the outlier test indicates no outliers in the dependent variable. To determine whether the collected data on students' competencies in critical thinking and mathematical representation followed a normal distribution within each group, normality tests were conducted. These evaluations were performed utilizing the IBS SPSS Statistics software. The analytical findings from these normality checks are tabulated in the "Test of Normality" section, specifically within the Shapiro-Wilk output, as demonstrated in Table 12.

Table 12. Results of the data normality test

Tested variables	*Asymp. Sig. (2-tailed)*			Exp.
	Experiment	Contrast 1	Contrast 2	
Pre_CriticalThinking	0,076	0,063	0,086	Normal
Post_CriticalThinking	0,054	0,090	0,269	Normal
Pre_MathematicalRepresentation	0,127	0,073	0,089	Normal
Post_MathematicalRepresentation	0,052	0,088	0,088	Normal

Table 12 shows that the Shapiro-Wilk significance value for the critical thinking and mathematical representation abilities of students in each research class is greater than 0.05. Therefore, it can be concluded that the pre-test and post-test data on students' critical thinking and mathematical representation abilities across all classes are normally distributed, and assumption 6 is fulfilled. Linearity testing was conducted to determine whether the relationship between the independent and dependent variables was linear. The linearity results are shown in the SPSS output presented in Figure 3.

ANOVA Table

			Sum of Squares	df	Mean Square	F	Sig.
BK * Kelas	Between Groups	(Combined)	93.056	2	46.528	.530	.590
		Linearity	88.889	1	88.889	1.013	.316
		Deviation from Linearity	4.167	1	4.167	.047	.828
	Within Groups		9213.194	105	87.745		
	Total		9306.250	107			
RM * Kelas	Between Groups	(Combined)	200.633	2	100.316	.610	.545
		Linearity	96.466	1	96.466	.586	.446
		Deviation from Linearity	104.167	1	104.167	.633	.428
	Within Groups		17276.294	105	164.536		
	Total		17476.927	107			

Figure 3. Linearity test results using SPSS software

Based on Figure 3, the significance value (Sig.) located in the Deviation from Linearity row is recorded as 0.828 for critical thinking and 0.428 for mathematical representation. Since both readings exceed the 0.05 threshold ($p > 0.05$), it is confirmed that a linear correlation exists between the predictor variable (independent) and the response variable (dependent), thereby satisfying the linearity assumption. Furthermore, homogeneity testing was conducted to verify whether the variances across the critical thinking and mathematical representation groups were equal. The outcomes of this homogeneity assessment are accessible within the Box's M Test of Covariance Matrices and the Levene's Test of Equality of Error of Covariance Matrices (Levene's Test). The standard decision rule for this test stipulates that if the significance value is greater than 0.05, the samples are considered to originate from the same population (homogeneous). Specifically, the results obtained from the Box's M test are tabulated in Table 13.13.

Table 13. Results of the homogeneity test analysis using Box'M test

Variable	Box'M	F	df1	df2	Sig.
Critical Thinking Ability and Mathematical Representation	24,806	1,172	20	39574,873	0,268

Based on the homogeneity assessment, carried out utilizing the Box's M test as shown in Table 25, revealed that the significance value obtained was above the 0.05 threshold > 0.05. This finding confirms the uniformity (homogeneity) of both the critical thinking skills and mathematical representation competencies among the study participants. This specific homogeneity analysis was a necessary step performed prior to determining the relationship (correlation) between critical thinking and mathematical representation capabilities. Subsequently, the outcomes of the multicollinearity analysis are provided in Table 14.

Table 14. Multicollinearity test results

X		Critical thinking	Mathematical representation
Critical thinking	Pearson Correlation	1	0,292
Mathematical representation	Pearson Correlation	0,292	1

Based on the results of the multicollinearity test shown in Table 14, all tested variables have a Pearson correlation of 0.292, which is less than 0.8 or 0.9, so there is no multicollinearity. Thus, this assumption is fulfilled. Therefore, we can proceed with the MANOVA test.

c. MANOVA test

The MANOVA procedure was performed using SPSS. This statistical test was conducted to assess the presence of significant variation in both critical thinking skills and mathematical representation capabilities. Furthermore, the resulting MANOVA analysis was conducted using Hotelling's Trace test to examine discrepancies among the distinct study groups. These analytical findings are cataloged in Table 15.

Table 15. MANOVA analysis results

Effect	Value	F	Sig.
Hotteling's Trace	0,678	17,448	0,000

Based on Table 15 in Hotelling's Trace, a sig. value of 0.000 was obtained, which is less than 0.05, meaning that H0 is rejected. Therefore, it can be concluded that each class (type of learning difference) influences critical thinking ability and mathematical representation ability simultaneously. Significant differences in means between independent and dependent variables can be analyzed through the Output Test of Between-Subject Effect in SPSS, as shown in Table 16.

Table 16. Results of the effect test between subject variables

Class	Variable	F	Sig.	Class	Variable	F	Sig.
Experiment Contrast 1 Contrast 2	Critical thinking	29,494	0,000	Experiment Contrast 1 Contrast 2	Mathematical representation	8,688	0,000

Table 16. A noteworthy disparity exists in both critical thinking skills and mathematical representation ability among students in the experimental group, compared with class 1 and class 2. This distinction is confirmed by a significance value below 0.05, which leads to the rejection of the null hypothesis H_0. Consequently, it is established that using the guided inquiry-based e-LKPD, integrated with the Liveworksheets, yields a statistically significant difference in students' critical thinking and mathematical representation proficiency compared with students who did not employ this specific learning tool.

1) Improvement in critical thinking ability and mathematical representation ability in each class

A pairwise comparison analysis was conducted to determine whether improvements occurred in both critical thinking skills and mathematical representation competency. This improvement was evidenced by the rise in students' pre-test and post-test scores observed across the experimental group, contrast class 1, and contrast class 2. The findings yielded by this inter-class assessment are documented in Table 17.

Table 17. Results of the pairwise comparison test

Variable	Class (I)	Class (J)	*Mean Difference* (I-J)	Sig.
Critical thinking	Experiment	Contrast 1	11,528	0,000
		Contrast 2	15,694	0,000
	Contrast 1	Experiment	-11,528	0,000
		Contrast 2	4,167	0,155

	Contrast 2	Experiment	-15,694	0,000
		Contrast 1	-4,167	0,155
Mathematical Representation	Experiment	Contrast 1	11,342	0,004
		Contrast 2	13,426	0,001
	Contrast 1	Experiment	-11,342	0,004
		Contrast 2	2,084	1,000
	Contrast 2	Experiment	-13,426	0,001
		Contrast 1	-2,084	1,000

Based on Table 17, the order of increase in critical thinking and mathematical representation ability of students from the highest order is the experimental class. There was a significant difference in the improvement of critical thinking ability between the experimental class and classes 1 and 2. This was proven by a sig value < 0.05. Meanwhile, contrast class 1 and contrast class 2 also showed improvement, but it was not significant. This also occurred in students' mathematical representation ability.

2) Effectiveness Test

The effect size test was conducted to determine the impact of guided inquiry-based e-LKPD on improving students' critical thinking and mathematical representation ability. The results of the effect size test are shown in Table 18.

Table 18. Effect size test results

Variable	Partial eta squared	Category Cohen's f
Critical thinking	0,360	Large effect size
Mathematical representation	0,142	Medium effect size

Based on Table 18, it is known that guided inquiry-based e-LKPD using the liveworksheet website affects the critical thinking ability of 0.360 (Cohen's f in the large effect size category) and the mathematical representation ability of 0.142 (Cohen's f in the large effect size category). These results indicate that e-LKPD, based on guided inquiry using the liveworksheet website, affects students' critical thinking and mathematical representation abilities. Therefore, the developed e-LKPD is effective in improving students' critical thinking and mathematical representation abilities.

Evalution

The assessment phase served as the final stage in developing the guided inquiry–based e-LKPD using LiveWorksheet. Its purpose was to evaluate whether the development goals had been achieved and to produce the final version of the product. The evaluation focused on the e-LKPD's feasibility, practicality, and effectiveness in improving students' mathematical representation and critical thinking skills on the topic of heat and heat transfer. The analysis showed that the e-LKPD was validated as feasible by experts, physics teachers, and academic peers. It was also considered practical, supported by positive student feedback from small-scale trials. Most importantly, it proved effective in enhancing students' critical thinking and mathematical representation abilities, as shown by N-gain scores of 0.78 and 0.74 in the experimental group that used the e-LKPD. Overall, the LiveWorksheet-based guided inquiry e-LKPD met the intended development objectives and was confirmed to be feasible, practical, and effective for improving student learning in heat and heat transfer.

This e-LKPD is provided as accessible links generated via Canva and Liveworksheet platforms, enabling its use on both smartphones and laptops. The construction of the e-LKPD was grounded in the Independent Curriculum currently adopted by educational institutions, simultaneously incorporating the Pancasila student profile principles. Structurally, the e-LKPD adopts the guided inquiry syntax, which encompasses: introduction to the problem, articulation of the problem, formulation of hypotheses, data gathering, data analysis, and assessment. The implementation of the Guided Inquiry learning model prioritizes the students' cognitive process of independently seeking and ascertaining solutions to a given issue. A key benefit of using the Guided Inquiry-based e-LKPD is its ubiquitous accessibility, which significantly facilitates learners' access to media. Consequently, the employed media is deemed highly practical for supporting student learning. However, a limitation of this e-LKPD learning resource is the requirement for a stable internet connection.

CONCLUSION

The findings from the developmental study of the e-LKPD, which used the Liveworksheet platform and incorporated the guided inquiry model, suggest that integrating this digital resource into the instructional process yields enhanced efficacy. Consequently, this integration significantly bolsters students' proficiencies, particularly in the domains of critical thinking and mathematical representation. In addition, it can help teachers incorporate innovation into a broader range of teaching materials in the learning process. However, several limitations need to be considered. First, the e-LKPD currently contains only material on heat and its transfer, so it needs to be expanded to include other sub-topics in accordance with students' learning needs. Second, the e-LKPD can only be accessed with an internet connection, and signal strength will also affect its use, as it is online-only.

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